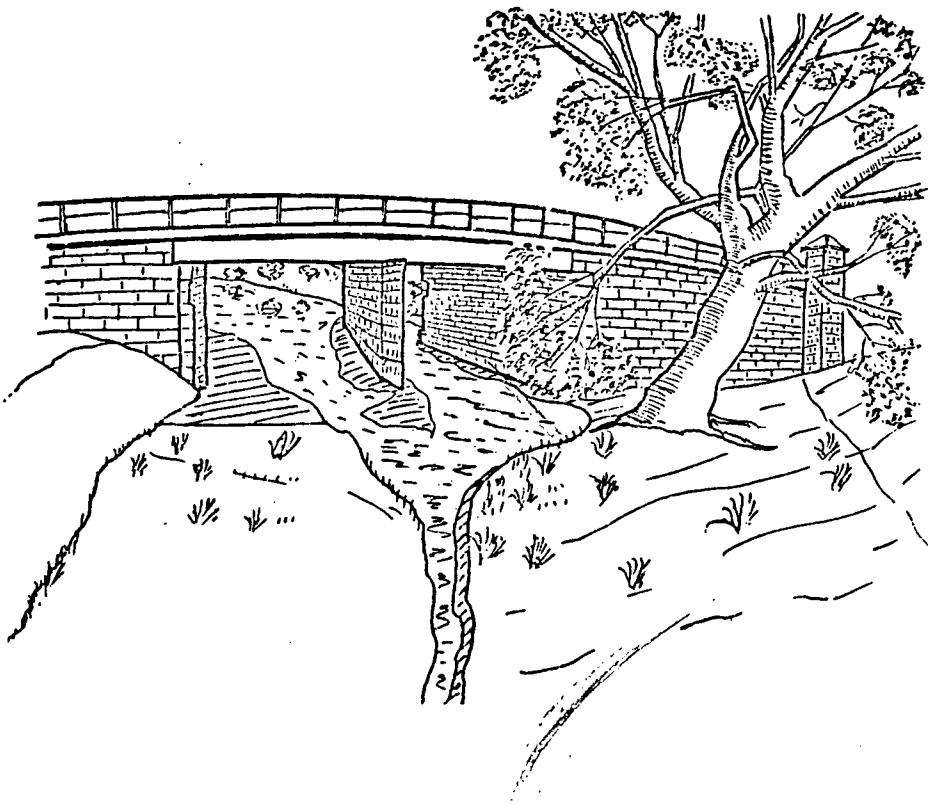
MAN AND RIVER

A PRELIMINARY STUDY OF FAECAL COLIFORMS IN TWO TASMANIAN RIVERS



P. E. SPRATT

J.W. FELGENHAUR

MAN AND RIVER:

A PRELIMINARY REPORT ON THE ORIGIN AND NATURE OF FAECAL COLIFORMS IN TWO TASMANIAN RIVERS.

J. John William FELGENHAUR
P. SPRATT
Peter Elliott

BEING A THESIS SUBMITTED IN PART FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENVIRONMENTAL STUDIES.

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PREFACE

This Report is very much of a preliminary nature. It is a first attempt to determine the relevant influences acting on a local river system in order to explain various phenomena of faecal coliform activity observed by others both locally and overseas. The work is intended to determine the important parameters controlling the coliforms in the systems being examined so that later definitive work can be clearly focused.

Our approach has entailed the establishment of a broad background picture of the environmental system in which the coliforms live and in which the tests for them have been determined. There is then, much which will not be needed for later detailed studies, but which must first be done in order to establish what is necessary and what is not.

Our scope has been greatly limited by restrictions of time, laboratory space and equipment, restricting work to only the winter months though it is perhaps a finding in itself that the summer months appear to be the most important.

The Report is written in a discursive style, and we have attempted to make each section and chapter as self contained as possible, so that persons unfamiliar with the field could, by repetition, gain some idea of the principles on which we have based our work.

We wish to thank out supervisors, Dr. R. Jones, Dr. T.A. McMeekin and Dr. D.A. Ritz of the University of Tasmania, and Dr. E.J. McArdle of the Department of Public Health, Tasmania. We give special thanks to Mr. R. Walters of the Water Research Laboratory, Bolivar, South Australia, for his advice on water quality techniques and methods.

SECTION A:

INTRODUCTION AND OVERVIEW

CHAPTER 1

INTRODUCTION AND OVERVIEW

This Preliminary Report has investigated certain aspects of faecal coliforms in the Jordan and Derwent Rivers in Tasmania. Faecal coliforms have been given importance as a result of overseas research as indicators of environmental health hazard. However, they themselves are affected by their surrounding environment and we believe that an objective assessment of them cannot be made without examination of the environmental system in which they exist. The system is that of Man, Microbe and River with each interacting to form the environment commonly occupied by all. In this Study we have endeavoured to take these interactions into account by not examining coliforms in isolation, but as part of the total system. We have then, looked at Man, River and Microbe in the context of their interaction, and it is from this viewpoint that this Study was undertaken.

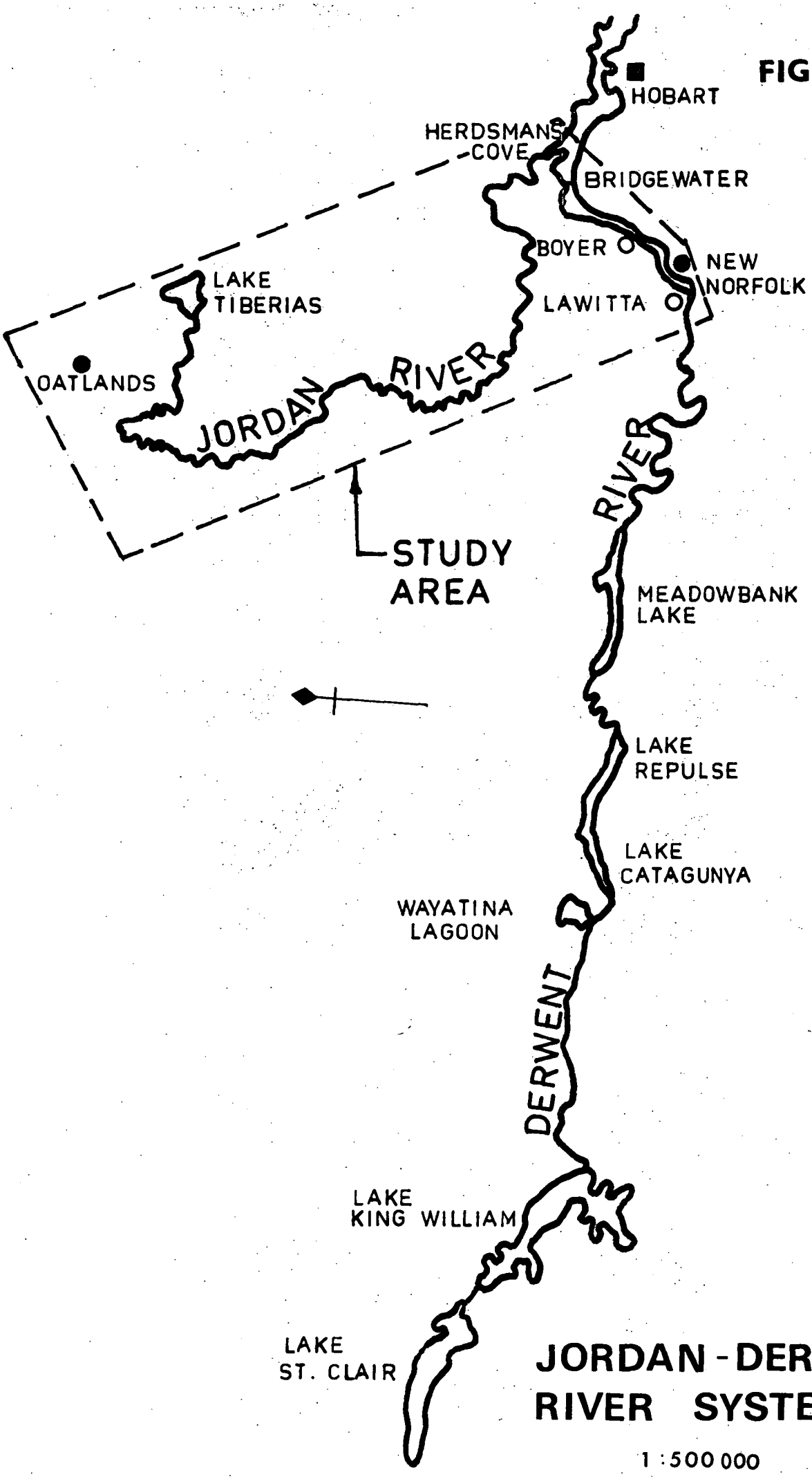
PURPOSE OF THIS STUDY

The two river system of the Jordan and Derwent as shown in Figure 1 was examined.

Our interest in the Jordan was aroused initially by the Tasmanian Department of the Environment's Annual Reports[1,2] which showed very high levels of faecal coliforms in the Derwent River at Bridgewater (Figure 2). The Report gave no reason for these coliform levels.

Bridgewater is adjacent to Herdsman's Cove, the entry point of the Jordan River into the Derwent, (Figure 3), and, after ~~on~~ checking statistics of the Jordan catchment,[3,4] we found it to have a population of 3,900 humans and 410,000 animals. It appeared to us that the faecal coliforms observed at Bridgewater might be of Jordan source and be substantially animal in origin. Testing of this hypothesis was available through the work of Geldreich[5] who had developed techniques in the U.S.A., using faecal coliform to faecal streptococci

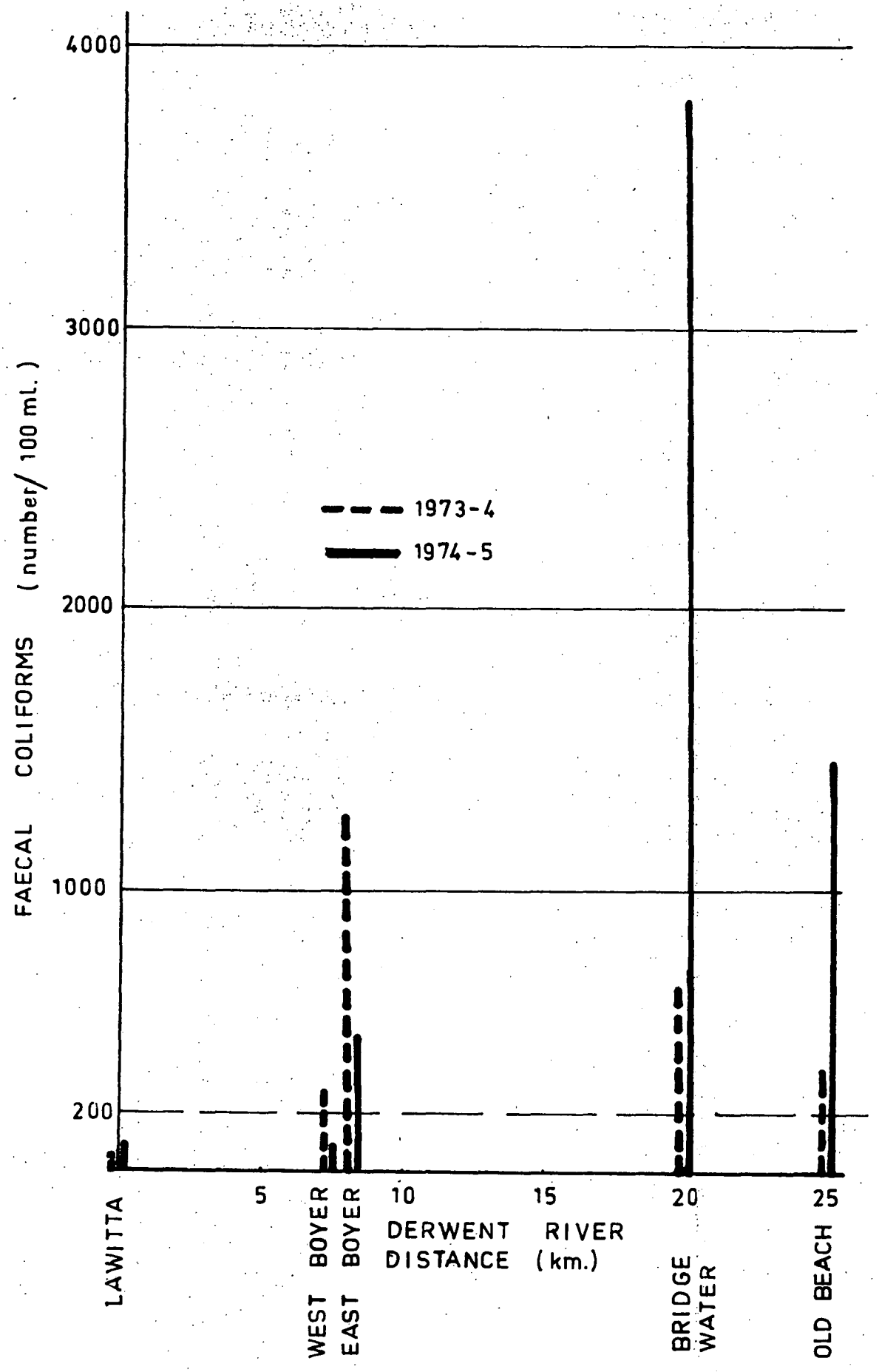
FIGURE 1



JORDAN - DERWENT RIVER SYSTEMS

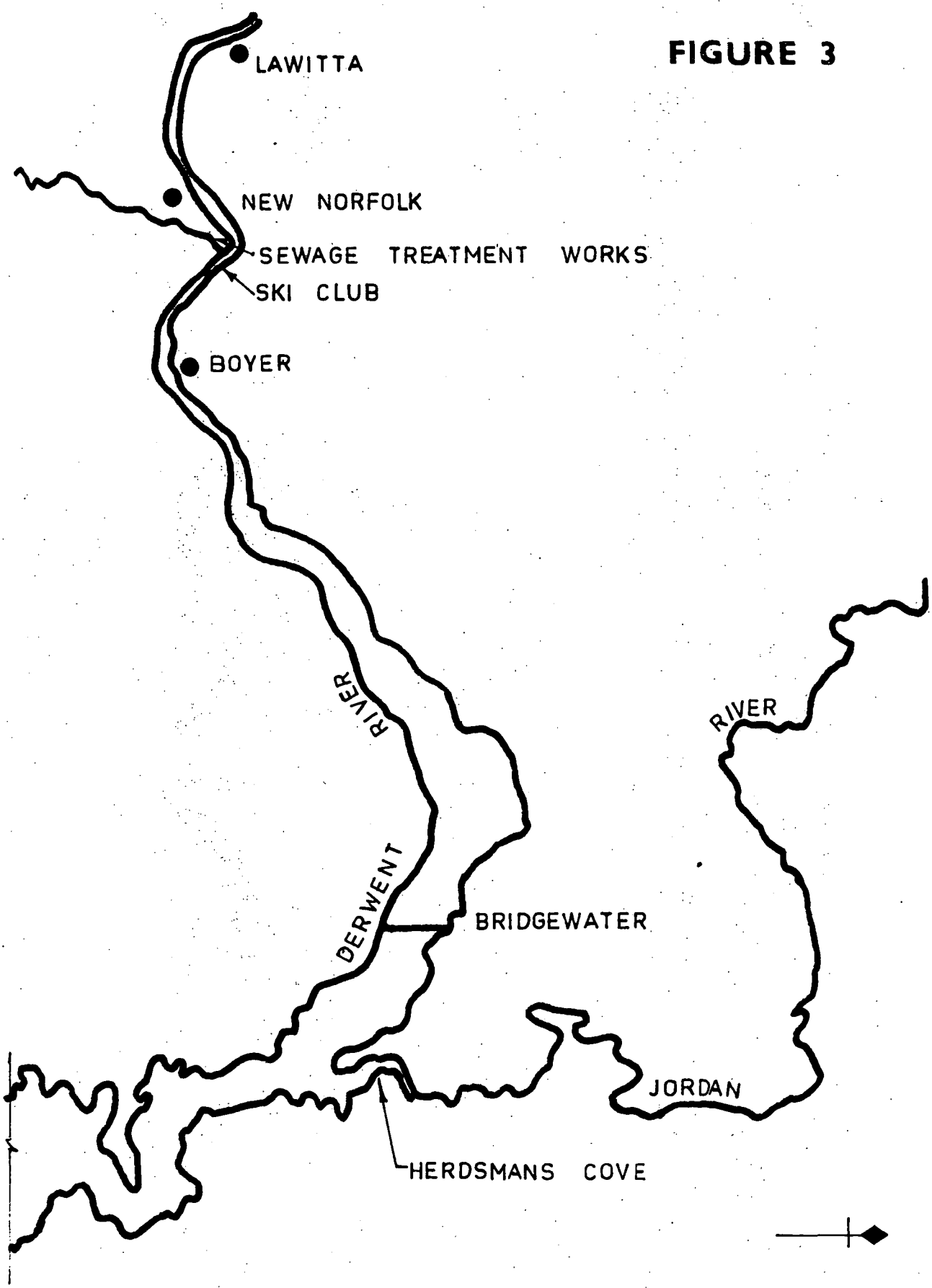
1 : 500 000

FIGURE 2



DERWENT COLIFORM COUNTS
D.o.E. REPORTS

FIGURE 3



CONFLUENCE
DERWENT AND JORDAN RIVERS

1 : 100000

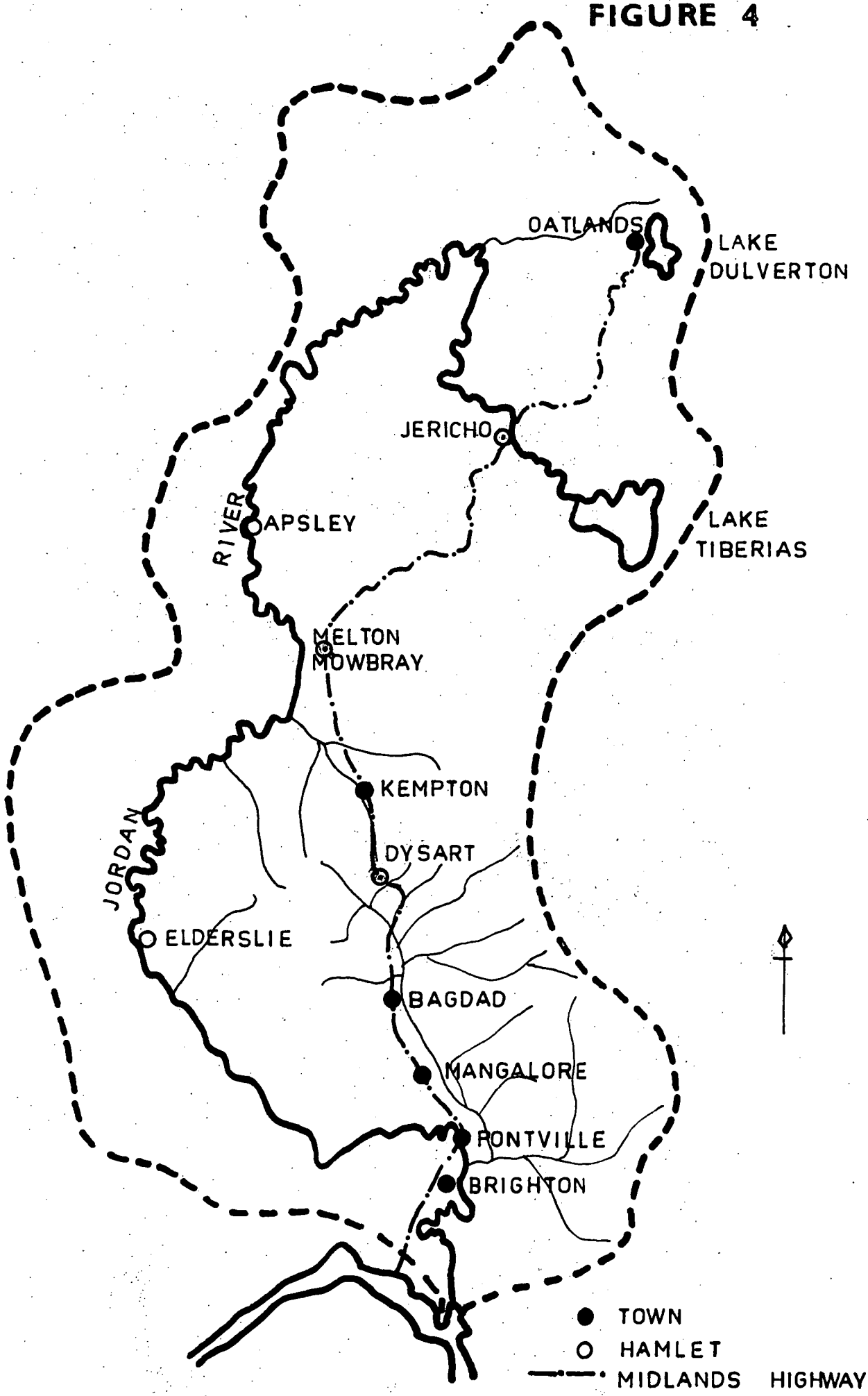
ratios, to differentiate between faecal wastes of humans and animals. Further, examination of the map of the Jordan catchment, (Figure 4), showed that the 113 kilometer length of the river included a number of small towns interspersed throughout its length, so it appeared likely that point sources of faecal pollution could be identified.

Additionally, Geldreich[6] had shown that pathogens were present in 27.6% of samples of fresh water tested where faecal coliform counts were 200 per 100 ml. or less and that for coliform counts of 200 to 2000 per 100 ml. the pathogen percentage increased to 85.2. This work of Geldreich supported the recommendation of the National Technical Advisory Committee on Water Quality Criteria of the U.S.A.[7] that 200 coliforms per 100 ml. should be the standard for waters in which humans come into primary contact by swimming, bathing, water skiing etc. Hart[8] had also recommended this as an Australian upper limit criterion, beyond which, in recreational waters, investigation should be made for health hazards. This linking of faecal coliform counts to possible health hazard greatly increased the value of our intention to check the Jordan for point source pollution.

As a further issue of interest, Bloom[9] had stated, 'organic matter, including untreated or partially treated sewage is known to be necessary in order to absorb mercury and other trace metals so that they can become part of marine food chains.' On this basis, Bloom advocated secondary treatment of human sewage wastes in the Derwent. It appeared to us that, if animal wastes proved to be a significant proportion of organic wastes, (Jordan River 3900 persons, 410,000 animals) then secondary treatment would not achieve the results expected by Bloom.

Finally, since the examination of our interests was relying heavily on overseas research, we considered it essential to endeavour to place it in the context of the local environment so as to provide a check with reality.

FIGURE 4



THE JORDAN BASIN

Our approach for this purpose has been to perform an examination of the local environment to provide a background against which to view the results of our testing. The Jordan River appeared ideal for this purpose with its small self contained catchment. The Derwent River from New Norfolk to Granton was considered necessary for faecal coliform comparison with the Jordan for it contained the large town of New Norfolk (pop.6800) which might have been the source of the large number of faecal coliforms observed by the Department of the Environment.

It was decided that the various elements comprising the Study purpose could be expressed by four aims.

AIMS OF THE STUDY

The determination of the origin of the faecal coliforms observed in the Derwent River around Bridgewater adjacent to Herdsman's Cove.

An assessment of the applicability of the Faecal Coliform to Faecal Streptococci ratio technique for differentiating between faecal wastes of humans and animals in the Derwent/Jordan system.

An assessment of health hazards in the Jordan/Derwent system as determined by criteria for faecal coliform counts.

A characterisation of the Jordan River Basin with regard to the interaction of Man and Environment and with the particular aim of providing a background against which to view the study results.

To set these aims into the context of the interaction between Man and River the growth of Man's understanding of the interactions was briefly examined.

MAN AND RIVER SYSTEMS

The earliest documented interactions between Man and River systems appear to have been in biblical Jericho in 7000 B.C.; in Mesopotamia in 4000 B.C.; and in Egypt in 3400 B.C.[10] In each case Man attempted large water storage projects as a counter to the lack of water caused by the aridity of these areas. Water storage was again Man's response to the environment with its unreliable rainfall in China during the Chou Dynasty of 1100 to 221 B.C.[11] Water management was the key to survival of these early communities. Some, as those along the Nile were successful to recent times, whilst others, as in Mesopotamia, succumbed in early history.[12]

The later civilisations of Europe have, at least until the last century, developed in contrast to the early civilisations. On the whole, since Europe has adequate rainfall for agriculture, irrigation was not widely practised and rivers came to be regarded as highways for commerce and recreation.[13] It was not until the middle of the Nineteenth Century, with its rapid industrialisation and population increase, that demand for water in Europe began to outstrip both its supply and its capacity. The resulting conflicts and problems forced European man to then consider water management and the environment. Table 1 sets out the development of the understanding by European Man of the Interaction between himself and his river systems.

The first considerations, those of the effect of water on man, have only very recently been extended to the present concern of man's effect on water. The recommended water quality criteria of the U.S.A.[14] and Australia[15] give special attention to standards of water quality for aquatic ecosystems, agriculture, livestock, industry and for recreational and aesthetic purposes. Concern is with the prevention or correction of nuisance resulting from the disposal of wastes; the preservation of the aesthetic

TABLE 1

Man and River - The Development of an Understanding

Date	Event
1845	John Snow - showed water to be transmitter of cholera.
1848	Edwin Chadwick. Poor Law Act. First description of interaction between human wastes and rivers.
1876	British Public Health Act prohibited discharge of human wastes to rivers.
1880	Von Fritsch - described *Klebsiella pneumoniae* and *K. rhinoscleromatis* as organisms typical of human faecal contamination.
1885	Escherisch - identified *Bacillus coli* (later *E. coli*) as an indicator of faecal pollution.
1898	British Royal Commission on Sewage Wastes appointed.
1901-1915	The publication of the Ten Reports of the Commission. 8th Report - First examination of rivers to determine what standards should be applied to wastes to prevent damage to river system. 9th Report - set standards for discharge of trade wastes to rivers.
1914	American Public Health Service first standard bacteriological test for coliforms.
1966	Geldreich. Report on the Sanitary Significance of Faecal Coliforms in the Environment.
1968	Publication of American Water Quality Criteria. Attention given to Man's effect on water in addition to water's effect on Man.
1974	Publication of Australian Water Quality Criteria. Attention again given to Man's effect on water in addition to water's effect on Man.

qualities of river systems; the suitability of river systems for agricultural, recreational, municipal and industrial wastes and the potential harm to the environment of river systems. It is now recognised that any study on a river system involving one particular aspect must bear in mind the relation of that aspect to the wider context of the complete system and the interactions between all the various aspects.

In European man the attitudes and concerns have developed in the short space of time since 1915; the scientific basis is still being expanded and is still in its youth; much remains to be done and much is still to be researched.

It was European man who settled Australia and, in particular, the Jordan Basin was settled by him in 1824.[16] This settlement predates the European change in attitude to water usage. It is of interest to note this fact and to realise additionally that Australia is the driest continent in the world.[17] As a matter of comparison,[18] the Australian annual rainfall averages 420 mm; the global 660 mm; the U.S.A. 740 mm and Europe 610 mm. As discussed later in this Report the average annual rainfall of the Jordan catchment is 556 mm., with important areas around 480 mm., so that we can already anticipate differences between the Study environment and those of Europe and the U.S.A.

We have used these considerations as a reference framework for this Study. We consider it important to acknowledge at the beginning that the Jordan is a different environment firstly to that from which its settlers came and secondly to that from which the coliform tests came. For these reasons we adopted the approach of preparing the environmental background simultaneously with, and in some instances prior to, the microbiological setting. This approach has, to a large extent, determined the Structure of this Report.

STRUCTURE OF THE REPORT

The discussion in the previous sections of Purpose of Study and Man and River Systems has highlighted the need to provide an environmental background against which to view both the results of our investigation and the techniques used in that investigation. The Jordan is the more convenient river to investigate from this viewpoint and hence has received detail study in preference to the Derwent. The Derwent has then been used for comparison with the Jordan and tested only insofar as was necessary for this purpose and for the aim of determining the source of faecal coliforms at Bridgewater.

The Report has been divided up into Four Sections. Section A is comprised of the Introduction and Overview. It gives the rationale of the Study and presents the major conclusions and recommendations. Section B discusses the physical environment of the Jordan Basin and man's use of the basin, and establishes the background against which the sampling and discussion are set. Section C deals with the microbiological setting and the sampling of the river systems whilst Section D is devoted entirely to discussion of the findings.

For convenience in obtaining a quick overall picture of the environmental background for reference use with Section C and with the discussion of Section D, a summary of the contents of Section B has been given at the beginning of that Section.

CONCLUSIONS

Our conclusions, as a result of this Study, are that:-

The Jordan River contributes few faecal coliforms to the Derwent. The 410,000

animals and 3,900 humans in the Jordan Basin contribute few faecal coliforms to the Jordan River.

Source of Coliforms

The major source of faecal coliforms in the Derwent River between Lawitta and Bridgewater is the paper pulp factory at Boyer.

The paper pulp waste is indicated as being a nutrient medium for these faecal coliforms.

Whilst the organisms in the paper pulp react positively as faecal coliforms to the Standard Methods (14th Edition) test a literature survey indicates that many of them may be Klebsiella pneumoniae

Certain strains of Klebsiella pneumoniae are pathogens in their own right. The significance of K. pneumoniae is that instead of faecal coliforms indicating indirectly the possible presence of pathogens, there is in this case the direct indication of a ~~probable~~ possible pathogen. It remains, however, to isolate pathogenic strains of Klebsiella pneumoniae from the effluent to prove a potential health hazard.

More research is needed to define the faecal coliform organisms, and the significance of each.

Faecal coliform to Faecal streptococci ratio

The presence of organisms in the paper pulp waste from Boyer which react positively to the faecal coliform test

prevents any assessment of the validity of this ratio in the region of the Derwent River studied by us.

Tests taken in the Derwent upstream of Boyer show Fc/Fs ratios as of human origin only directly downstream of the New Norfolk Treatment Plant and on the same side of the river as the Plant. Midstream and opposite river bank tests at the same location did not usually give ratios indicating faecal wastes of human origin. We attribute this to lack of mixing of river waters. Further downstream where mixing occurs the tests are obscured by Boyer wastes.

We expected the imbalance between animals and humans in the Jordan Basin to show up in Fc/Fs ratios being more strongly biased towards animals. The results show unexplained fluctuations. The reasons are thought to lie in environmental conditions in the catchment. It is considered that the general aridity and the long flow paths from origin of coliforms to river water are the major reasons. Holding mechanisms in the soils and/or predation are among other possible reasons.

We conclude that the Fc/Fs ratio test is inconclusive in the areas studied by us (for the reasons given). It is evident that great care needs to be taken in using this test and that it should be used only with due regard to local environmental conditions.

Health Hazards

Our literature research indicates that the present criteria for correlation between definite health hazard and faecal coliform levels is inadequately based and requires further research work.

Given the above, based on present recommended criteria for primary body contact recreational waters of 200 faecal coliforms per 100 ml., the following locations are indicated as being possible health hazards, and requiring further assessment, ~~during the recreational season:-~~ during the period of investigation, including during the recreational season

Derwent River (i) Out from the New Norfolk Rowing Club boat ramp ~~during the summer months~~.

(ii) The South bank adjacent to the New Norfolk Sewage Treatment Plant, ~~at all times of the year~~ and the nearby water ski club on the opposite bank, ~~at times of low river flow.~~

(iii) All parts of the river downstream of Boyer to Bridgewater, ~~at all times~~.

(iii) the River downstream of Boyer to upstream of the ski club from June to September (Survey Period). Following further work the hazard area may be extended further downstream to Bridgewater & the period to all times of the year.

Jordan River The Ford at Pontville and the Conservation Area at Herdsman's Cove at all times.

Man and the Jordan

It is our opinion that the general aridity, the poor soils and the steep terrain of the Jordan have controlled and will continue to control Man's use of the region.

No areas of the Jordan Basin have sufficient rainfall to ensure adequate crop growth during the growing season. Irrigation is necessary even at Bagdad (615 mm. average rainfall) to ensure sufficient water for this purpose.

If a water storage for irrigation is constructed it is likely to be at Kempton for the following reasons:-

(i) This site is favoured by the Rivers & Water Supply Commission.

(ii) The Kempton Valley has some of the better soils of the Basin.

(iii) Three months irrigation only is required in the Kempton Valley as against five months on similar soils around Brighton.

(iv) The subdivisional development around Brighton is thought to preclude its future use for agriculture.

If water storage is provided and irrigation increased it can be anticipated that faecal coliforms will increase in the Jordan from additional run off in the Green Ponds, the Bagdad and the Strathallan Rivulets.

RECOMMENDATIONS

It is traditional that, whenever any subject is studied, the first recommendation is - "further work is needed". Nevertheless we feel that further work is indeed needed and that, furthermore, priority should be given to the Derwent River. Our Study has had the great constraints of the shortness of available time and of the fact that the winter season was the only full season available. Consequently, to obtain a complete and definite picture it is essential that the works as recommended be undertaken for at least a full year. The constraints upon us and the need to extend this Study are reflected in our recommendations. We believe that the Derwent should receive priority because our conclusions show it to be of major importance relative to the Jordan and because it poses the major questions.

For the Derwent River we recommend:-

A detailed analysis of the effluent from the Boyer paper pulp mill to determine:-

a) The nutrients present both as to constituents and to quantity. This is essential not only to determine the potential for microbial growth but also to establish data necessary for nutrient removal.
b) The species present in the microbial population; their origin and their ecology.
   This is essential to determine the health hazard potential and to obtain sufficient understanding to formulate and implement whatever controls which might be desirable.

A study of the patterns of illness of those workers at Boyer whose work brings them into intimate and prolonged contact with the effluent. This is necessary for obtaining a correlation between health and health hazard if the hazard is shown to exist by the microbiological work above.

Sampling of the river waters from New Norfolk to Bridgewater, in particular during the summer months when human water contact is likely to be most frequent and when river temperatures best suit microbial requirements.
The sampling suggested is:-

a) For indicator organisms and enteric pathogens. It is desirable to link this with an epidemiological survey ~~or~~ of river users to more precisely define the present water quality criteria with regard to faecal coliform counts.
b) For establishing the variations in numbers of indicator organisms in the river below Boyer and hence to obtain an idea of their multiplication, die off, environmental requirements etc.

For the Jordan River we recommend:-

An investigation of the mechanisms which are causing the low faecal organism counts observed in the River. It is thought the low count is due largely to environmental conditions in the soil but predation either in soil or creek/river water may be significant. Studies of the microbiology of the soils, animal distribution, run off patterns and creek/river microbial ecology are needed.

The above investigation to be linked to:-

a) An investigation of the likely impact of increasing animal populations on irrigated pastures so that control measures can be formulated and implemented if found necessary.
b) An investigation of the recreational amenity of the Jordan in the Herdsman's Cove Conservation Area and the likely effect of increase in human activity.
c) A sampling ~~of~~ for pathogens in the River from Pontville Ford to Herdsman's Cove during the summer months.

1 *DEPARTMENT OF THE ENVIRONMENT, 1974;*
Report for Year 1973-74;
Government Printer, Tasmania.

2 *DEPARTMENT OF THE ENVIRONMENT, 1975;*
Report for Year 1974-75;
Government Printer, Tasmania.

3 *AUSTRALIAN BUREAU OF STATISTICS, TASMANIA, 1976;*
Compendium of Municipal Statistics 1975, pp.10-12;
ABS, Hobart.

4 *AUSTRALIAN BUREAU OF STATISTICS, TASMANIA, 1977;*
Agricultural Industry, pp.28-31;
ABS, Hobart.

5 *GELDREICH, E.E., 1966;*
Sanitary Significance of Faecal Coliforms in the Environment;
U.S. Department of the Interior, Federal Water Pollution Control Administration, Washington,D.C.

6 *GELDREICH, E.E., 1970;*
Applying bacteriological parameters to recreational water quality;
Journal of the American Water Works Association 62: 113-120

7 *NCWQ, 1968*
Report of the National Technical Advisory Committee on Water Quality Criteria, p.12;
Federal Water Pollution Control Administration, U.S. Department of the Interior, Washington.

8 *HART, B.T., 1974;*
A Compilation of Australian Water Quality Criteria, p.165;
Australian Water Resources Council Technical Paper No.7;
Australian Government Publishing Service, Canberra.

9 *BLOOM, H., 1975:*
Heavy Metals in the Derwent Estuary, p.21;
Chemistry Department, University of Tasmania.

10 *VALLENTINE, H.R., 1967;*
Water in the Service of Man, p.22;
Penguin Books Ltd., Harmondsworth, Middlesex, England.

11 *TECLAFF, L.A., and TECLAFF, E., 1973;*
A history of water development and environmental quality, p.28;
in: GOLDMAN, C.R., McEVOY, J., RICHERSON, P.J., (eds.);
Environmental Qyality and Water Development, pp.26-77;
W.H. Freeman and Company, San Francisco.

[12] *JACOBSEN, T., and ADAMS, R.M, 1971;*
Salt and Silt in Ancient Mesopotamian Agriculture; in:
DETWYLER, T.R., (ed.);
Man's Impact on the Environment, p.383-393;
McGraw-Hill, New York.

[13] *TECLAFF and TECLAFF, 1973; po.cit., p.72*

[14] *NCWQ, 1967; op.cit.*

[15] *HART, 1974; op.cit.*

[16] *SCOTT, P. 1965;*
Land Settlement; in:
DAVIES, J.L., (ed.);
Atlas of Tasmania, pp. 42-5;
Lands and Surveys Department, Hobart.

[17] *MUNRO, C.H., 1974;*
Australian Water Resources and Their Development, p.104;
Angus and Robertson, Sydney.

[18] *Ibid.*

SECTION B:

MAN AND THE JORDAN

MAN AND THE JORDAN

In this Section we have carried out a broad appraisal of the interaction of Man and the Jordan. Since our purpose was to provide sufficient data for optimum choice of sites, and to provide an environmental background for interpretation, we have only examined those aspects considered useful for that purpose. It is recognised that for definitive and precise work a detailed study is necessary. However, such detailed study is only practicable after the important aspects have been determined and this is possible only after preliminary work has identified those aspects. This Section of the Report then is very much in the nature of a preliminary work.

The Section has been divided into two parts - the physical environment and man's use of the land. Since it was necessary to have it in a form readily usable for reference with the sampling and its interpretation, ~~it was found~~ for convenience ~~to present the two parts in a summary form of the important items~~. summaries of important items precede each of the parts of the Section.

SUMMARY

The Physical Environment

The River is located towards the Eastern boundary of its catchment.

The major length of the River is remote from areas used by Man.

Lake Tiberias and Lake Dulverton contribute little or no flow to the River.

The River has only four major catchments, two of which discharge at a common point at the Ford at Pontville.

Jurassic dolerite occupies 55% of the Basin with Triassic-Jurassic sediments occupying 35%.

Podzolic soils on dolerite occupy 50% of the Basin with podzolic soils on sandstones-mudstones occupying 30%.

The soils of the Basin are poor. Best soils are the brown soils on dolerite basalt which occupy only 10% of the Basin.

The Basin is a region of Tasmania's lowest rainfall. Average rainfall for the catchment is 556 mm. with highest at Rotherwood (727 mm.); Melton Mowbray has 482 mm. and Brighton 484 mm.

The Basin is within the region of Tasmania's highest mean maximum January temperature of 23°C. The mean minimum July temperature of the Basin varies from 1°C to 2.5°C.

The Basin is within the region of Tasmania's highest evaporation which varies from 1100 mm. at North and South ends to above 1200 mm. in the centre of the Basin.

The major portion of the Basin is savannah woodland. There are areas of dry sclerophyll forest but no areas of wet sclerophyll forest.

Irrigation is required for three months of the year at Oatlands and Bagdad and for five months at Brighton if effective plant growth is to be assured.

Man's Use of the Basin

Man has artificially subdivided the Basin into three Municipalities. Almost the whole of each of the Municipalities of Brighton and Green Ponds and 33% of Oatlands lie within the Basin.

The major centres of man's activities are located along the Midlands Highway and are remote from the River.

There are 3,900 humans and 409,859 animals in the Basin.

The animals excrete 750 tonnes of faeces per day compared with 0.59 tonnes by man.

The animals excrete 1,000 times as many faecal coliforms per day as man and 10,000 times as many faecal streptococci.

Of the total land area of the Basin only 38% is used directly by man.

CHAPTER 2

THE PHYSICAL ENVIRONMENT

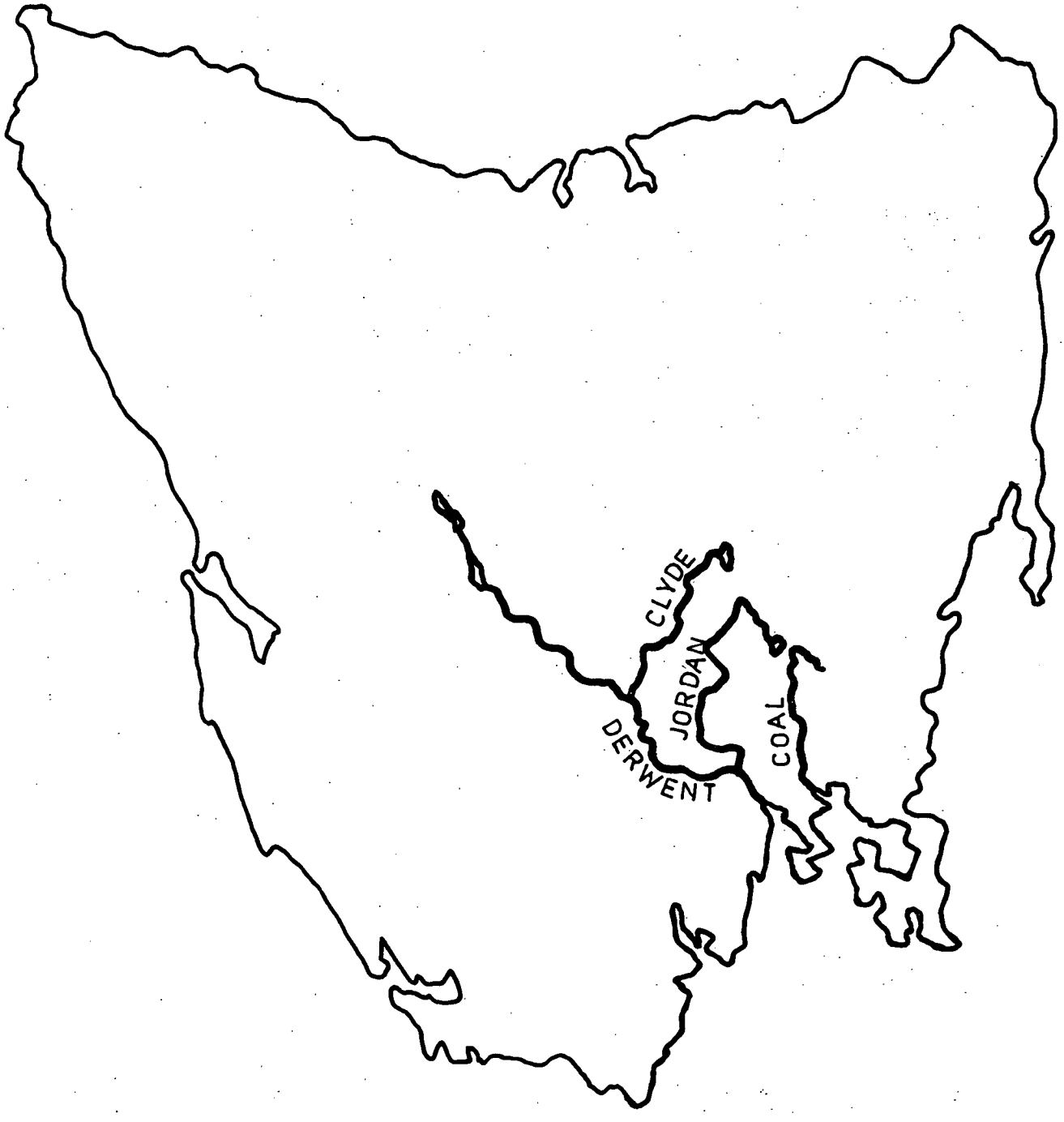
The purpose of this Chapter is to categorise the physical characteristics of the River as they affect the environmental setting for Man and Microbe. We have considered the location and formation of the River; the geology and soils of the Basin both [redacted] type and location, and the climate of the Basin. These characteristics, to a large extent, determine the use to which Man can put the Basin, since the interrelation between climate, geology and soils not only controls the native vegetation but also imposes restraints upon man and his plantings. These restraints in turn will determine population patterns of both man and animals and consequently also the distribution of their faecal bacteria.

LOCATION AND FORMATION OF THE RIVER

Location.

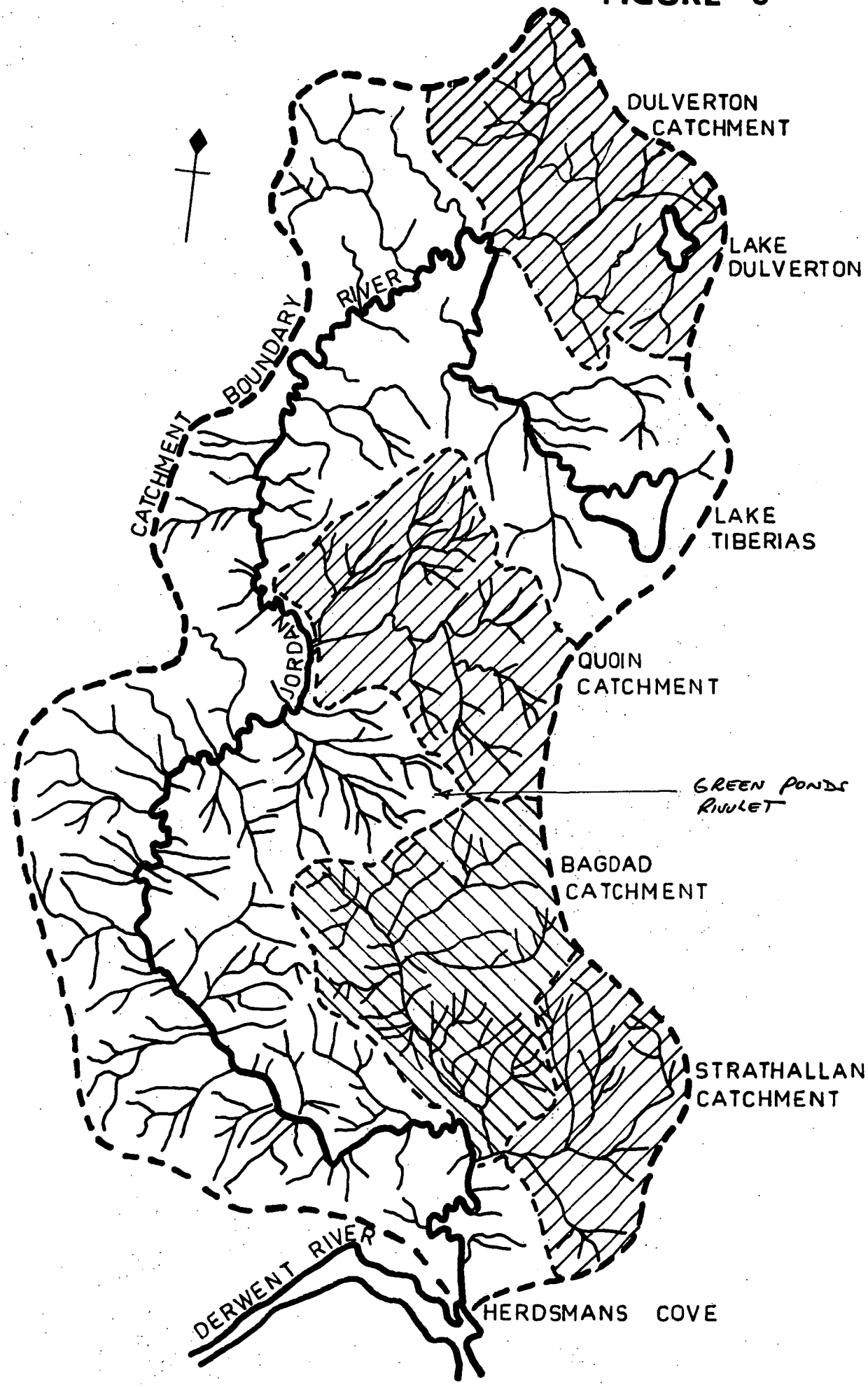
The Jordan is the central river of the three river system, the Clyde, Jordan and Coal, draining the Southern section of the Midlands region of Tasmania (Figure 5). The Jordan is approximately 113 kilometres in length with nominal source at Lake Tiberias, about 430 metres above sea level. The River follows a sinuous course Northwest to North for several kilometres before turning West and then South to join the Derwent River at Herdsman's Cove, East of Bridgewater. The Jordan drains a catchment of some 136,000 hectares divided up into 125 sub-catchments of which only 4 are of any size (Figure 6). The major physical characteristics of the Basin, demonstrated in Figure 6, are the offset of the River to the Eastern boundary of its catchment and the great number of small drainage basins forming the catchment. The Basin includes two lakes, Tiberias and Dulverton (Figure 6).

FIGURE 5



CLYDE-JORDAN - COAL
RIVER SYSTEMS

FIGURE 6



JORDAN CATCHMENT

1 : 250 000

Lake Tiberias.

This Lake has been described by Nye[1] and subsequently detailed hydrogeographically by Leaman[2]. Both state the Lake to be shallow with 90-95% of its water surface occupied by sedges. Leaman states annual rainfall to be 558 mm. with annual evaporation of 1000-1300 mm., and attributes the Lake's existence as due only to the existence of a shallow depression formed during the Quaternary era of the post Pleistocene period. Davies[3] regards the Lake as being of pre-glacial origin formed from the derangement of an older drainage system and hence predating the Pleistocene period. The Lake has a surface area of 800 to 1300 hectares and a catchment, including the Lake, of 2400 to 2700 hectares.[4,5] Because of water losses due to evaporation, evapotranspiration and leakage, the water level of the Lake is normally below the level of its outlet to the Jordan River.[6] Neither Nye nor Leaman or the Rivers and Water Supply Commission[7] attribute any importance to the Lake as a water storage for Man's use other than its value in the maintenance of water tables in its adjacent area.

Lake Dulverton.

This Lake is similar to Lake Tiberias.[8] It has a surface area of 220 hectares and a catchment of 3400 hectares. Evaporation exceeds rainfall and the Lake seldom contributes water to the Jordan. The Lake is a Conservation Area. No importance is attached to the Lake for water storage.[9]

Whilst the township of Oatlands is situated on Lake Dulverton and has a sewerage system, the effluent does not discharge to the Lake. We found by site inspection that a lagoon sewage treatment plant located on the West side of the town discharged its effluent to a creek flowing into the Dulverton Rivulet and thence to the Jordan River.

Formation of Basin.

Nye[10] has suggested that the topography of the Jordan Basin has been controlled by the twin factors of geological structure and rock types. He suggests that the surface slopes and boundaries of the catchment were defined by the end of Triassic-Jurassic sedimentation. In the geological time since, the comparatively soft Triassic-Jurassic strata were eroded to expose the underlying Permo-Carboniferous strata and the Jurassic dolerite. The softer Permo-Carboniferous strata was then preferentially eroded so that the River course tended to follow the junction of soft Permo-Carboniferous and hard dolerite. When this was not possible and the River was forced to erode a course through the dolerite it formed deep sided gorges in contrast to the flat open valleys in the sedimentary rock formations.

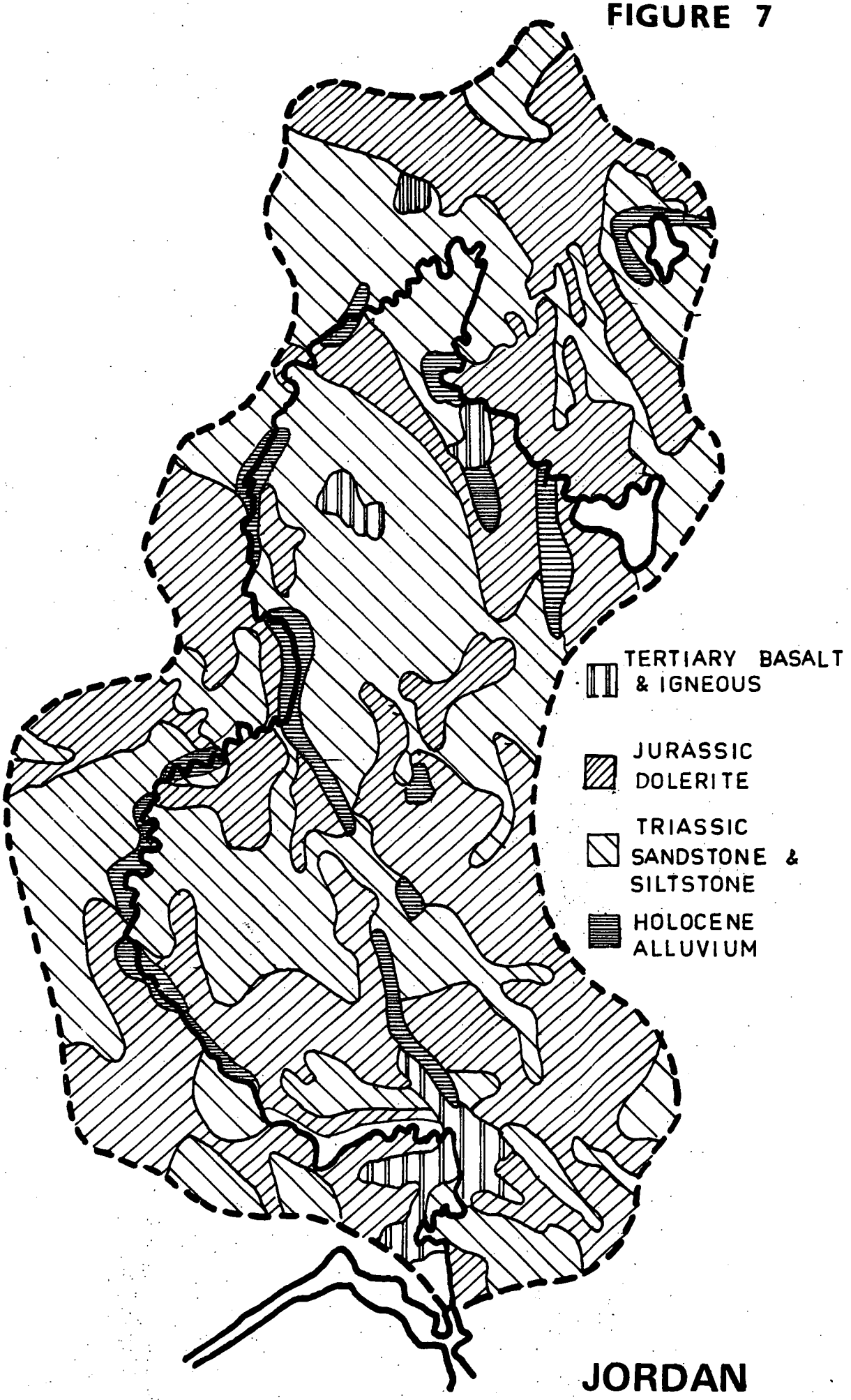
Geology.

Figure 7, compiled from geological maps,[11] shows the major geological formations of the Basin. Figure 7 and Figure 8, a longitudinal section plotted along the River centre line, tend to show the influence exerted on the River's formation by the dolerite. Stevenson[12] has commented on the general association of dolerite with river gorges and on the geological domination of the catchment by dolerite. Nye,[13] has given the percentage of the catchment surface area occupied by the major rock formations as being:-

Jurassic dolerite	55%
Triassic-Jurassic sediments	35%
Permian-Carboniferous	4%
Tertiary Basalt	3%
Tertiary Sedimentary	1%

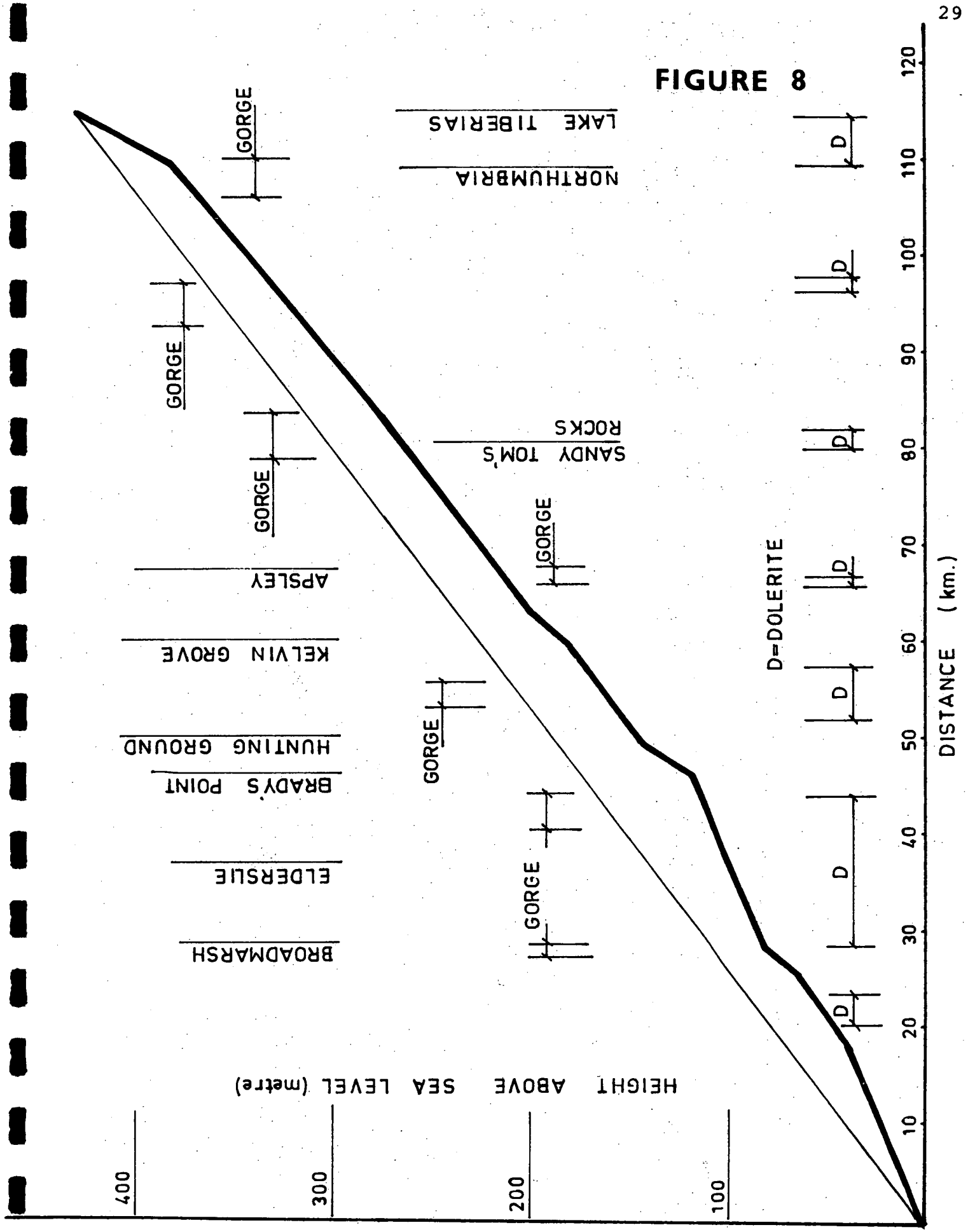
The alluvium of the Holocene period of the present Quaternary era is of interest due to its remote location from the River (Figure 7). This alluvium is not only on the course

FIGURE 7



JORDAN GEOLOGY

FIGURE 8



JORDAN RIVER
LONGITUDINAL SECTION

of the River from the Kempton Southwards, but follows the course of the Kempton-Mangalore valleys of the Bagdad Rivulet. It is these valleys which form the presently used alluvial soil plains.

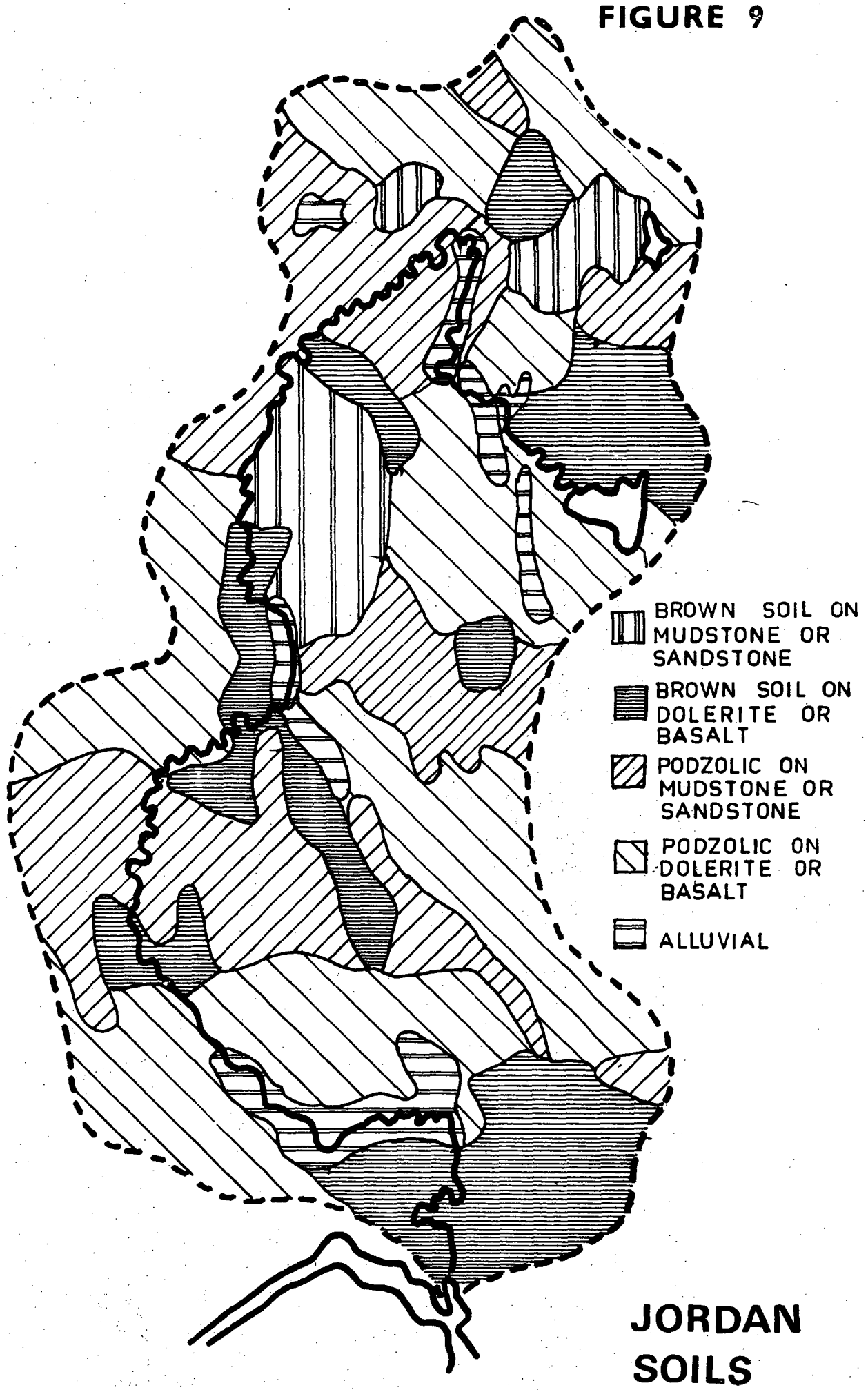
Soils of the Basin.

The soils of the catchment were initially described by Nye[14] and subsequently detailed by Dimmock[15] and Cowie.[16,17] The data from these works has been used to produce Figure 9. Nye appears to have used the soil classification of Jensen,[18] based on the geological nature of soil parent material, whilst Dimmock and Cowie have used Prescott's system[19] as derived from the Russian system of soil classification and adapted in light of Australian experience, mainly by Stephens.[20] We have used the classification of Dimmock and Cowie whilst noting the close relation between existing soils and basic geology in the Basin as originally stated by Nye. Figure 9 indicates that the podzolic soils on dolerite form about 50% of the soil surface area of the catchment with an additional 30% formed by podzolic soils on sandstone and mudstone. It is estimated that around 10% of the area's soils are brown soil on dolerite or basalt with around 8% being brown soil on sandstone-mudstone and 20% being alluvial. The podzolic soils on dolerite are indicated as occurring at elevations up to 700 metres wherever the rainfall exceeds 635 mm.[21,22] The brown soils on dolerite are associated with the drier parts of the area up to 300 metres.[23] Nye[24] classes the brown soils on basalt around the Brighton area as the best but mentions its shallow depth. Nye, Dimmock and Cowie all state the catchment has poor soil generally, particularly on the hillsides.

CLIMATE

The climatic aspects of rainfall, temperature and evaporation have been examined.

FIGURE 9


BROWN SOIL ON MUDSTONE OR SANDSTONE
BROWN SOIL ON DOLERITE OR BASALT
PODZOLIC ON MUDSTONE OR SANDSTONE
PODZOLIC ON DOLERITE OR BASALT
ALLUVIAL
JORDAN SOILS

Rainfall.

The Jordan catchment is in the region of lowest rainfall in Tasmania.[26] There are 16 rainfall stations in the catchment; rainfall varies from 727 mm. at the highest station (Rotherwood: 480 m. elevation) on the Eastern slopes of Table Mountain, to 482 mm. at Melton Mowbray. The average rainfall over the catchment is 556 mm. from the stations as shown in Figure 10.

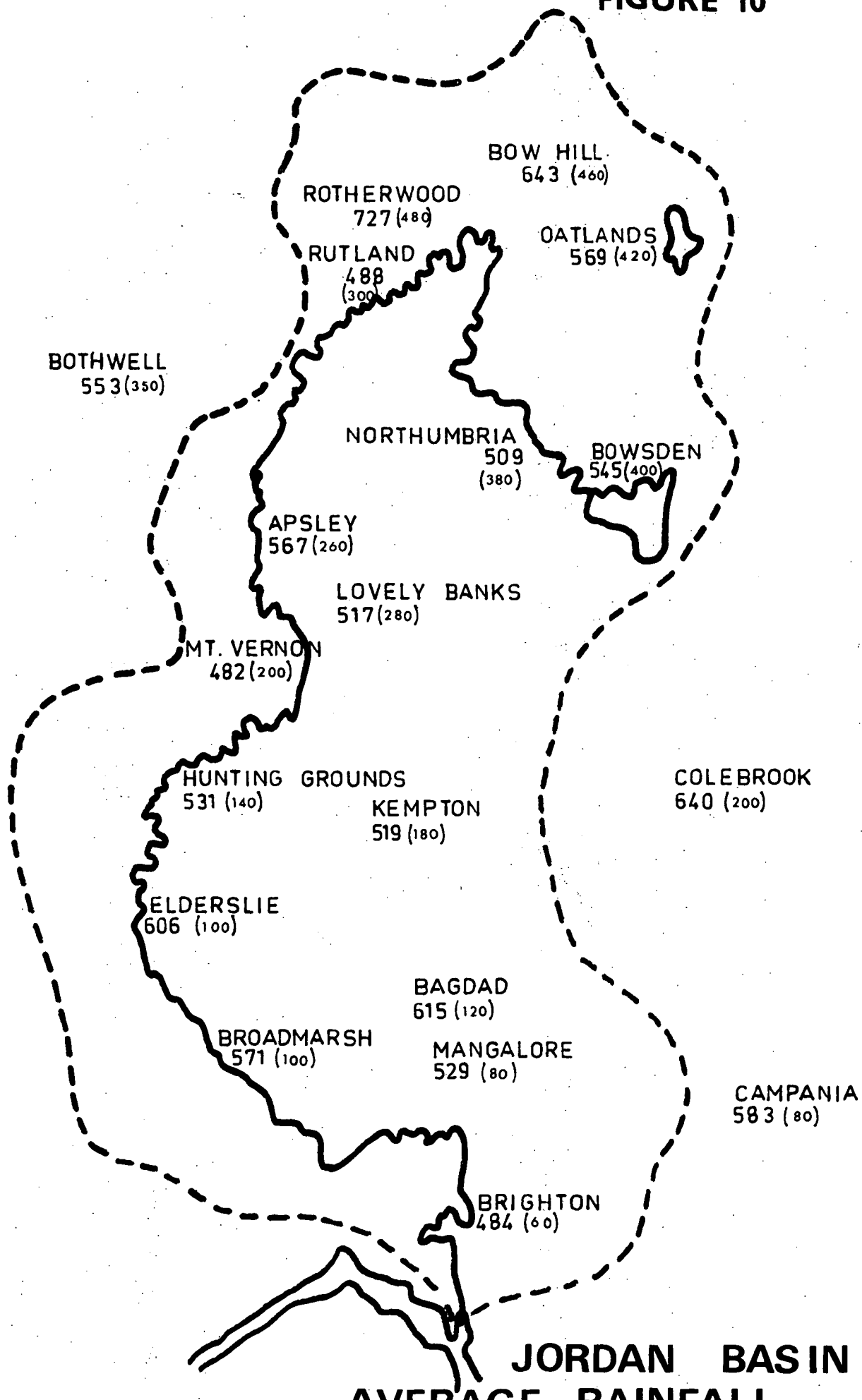
Table 2 shows the seasonal distribution of rainfall at the catchment stations.

TABLE 2

Jordan Catchment - Average Annual Rainfall

Location	Summer	Autumn	Winter	Spring	Total Annual
Bow Hill	165	167	151	171	643
Rotherwood	178	180	179	190	727
Oatlands	143	137	141	148	569
Rutland	128	124	114	122	488
Bowsden	137	135	131	142	545
Northumbria	121	131	121	136	509
Apsley	131	138	146	152	567
Lovely Banks	130	127	123	137	517
Mt. Vernon	119	123	115	125	482
Hunting Ground	132	136	132	131	531
Kempton	125	129	129	136	519
Elderslie	142	160	148	156	606
Bagdad	155	152	142	164	613
Mangalore	153	175	135	140	529
Broadmarsh	132	139	145	155	571
Brighton	126	122	111	125	484
			Catchment Average Rainfall		556

FIGURE 10



JORDAN BASIN
AVERAGE RAINFALL

RAINFALL 484
HEIGHT ABOVE SEA LEVEL (60)

The rainfall is markedly evenly distributed throughout each season of the year, particularly for the Hunting Ground station which has a difference of only 5 mm. between maximum and minimum seasonal rainfall. The seasonal rainfall pattern is shown in Table 3.

TABLE 3

Jordan Rainfall Stations - Rainfall Patterns

	Maximum Rain			Minimum Rain		
	Spring	Autumn	Summer	Summer	Autumn	Winter
No.Stations	11	2	2	4	1	10

It is seen then that no stations in the catchment receive their maximum rain in winter and that winter rains are least in 10 of the catchments. Nye[27] has commented on the rainfall pattern and suggested that the difference between stations in rainfall patterns is due to the superimposed South South Easterly influence on the prevailing Westerly influence acting together with local topography at each station and he considers the orientation of the river valleys to be of prime importance. The interaction of prevailing winds, rain shadow effects and of valley alignment do seem to explain the low rainfalls of Brighton, Kempton, Mt. Vernon and Rutland.

Temperature.

The Jordan catchment is within the region of the highest Tasmanian January mean maximum temperatures of around 23°C.[28] The mean minimum temperatures of July vary from 1°C to 2.5°C with 1.2°C occurring at Oatlands.[29]

Evaporation.

There are no evaporation stations in the catchment, the nearest being at Hobart and Lake St. Clair. The Rivers and Water Supply Commission[30] have calculated evaporation rates

for proposed dams and we have used their method to calculate expected average monthly evaporation rates at Oatlands, Bagdad and Brighton as being representative areas of the Basin. The method and the calculations are given in Appendix 1. We find that evaporation exceeds rainfall in Oatlands in every month excepting May, June, July and August; in Bagdad for every month excepting April, May, June, July and August and in Brighton for every month excepting June and July.

Effective Rainfall.

We have used the concept of effective rainfall to calculate the length of the plant growing season as determined by moisture conditions. Effective rainfall is defined as the amount of rainfall necessary to promote plant germination and to maintain plant growth above the wilting point. Prescott[31] has related effective rainfall to evaporation by the equation:

$$\frac{P}{E^{0.7}} = 0.54$$

where P is the effective rainfall and E is the evaporation. Prescott et alia[32] used values of the index $P/E^{0.75}$ to estimate the length of the growing season and found that it can be expressed as the time period during which the index $P/E^{0.75}$ exceeds 0.4. Loveday[33] suggests that monthly values of this order are not sufficient to maintain vegetation even if low transpiration and mist be supported by substantial periods of time when values of the index are 0.8 or more. The calculations and discussion are given in Appendix 1. We find that irrigation is required at Oatlands in January, February and March; at Bagdad in January, February and possibly part of March and at Brighton from November through to and including March.

Vegetation.

The vegetation of the Basin has been commented upon briefly by Nye[34] who gave a general description of the veg-

etation types found by him in the various regions of the Basin. Loveday,[35] who has examined in detail the vegetation in the adjacent valleys of the Coal, Orielton and Carlton Rivers, states that the vegetation of those areas can be divided into three main types dependent upon rainfall. Jackson[36] included elevation with rainfall, aspect and soil type as determining the vegetation types generally in Tasmania. On a broad basis, where rainfall is less than 635 mm. the characteristic vegetation is savannah woodland, while with rainfall greater than 635 mm. a dry sclerophyll forest develops. Beyond 760 mm. of rainfall the forest is described as wet sclerophyll. There is typically a gradation between these vegetation classes.[37,38]

Our own observations indicate most of the Basin within the immediate vicinity of the sampling sites can be classified as savannah woodland which has been cleared and put down to pasture.

ENVIRONMENTAL SUBDIVISION OF THE BASIN

Our aim has been to gather sufficient data on the physical environment to provide a picture of the constraints exerting major influence on Man's use of the Basin. In addition to the constraints of river geometry, soils and climate, we consider a major constraint to be Man's committment to wheeled vehicles. These vehicles cannot readily traverse ground slopes steeper than 1 in 5.[39,40] Figure 11 has been drawn dividing the Basin into areas of ground slope steeper and less than 1 in 5. We expect this Figure to provide a major environment division of the Basin and that a close correlation will be evident between ground slope and activity of man. As we are interested in these activities and their interaction with the River System we have produced Figure 12 showing ground slopes, roads and rivulet systems. From examination of Figures 7 to 11 we anticipate that Man's activities will be centred in the Oatlands -

FIGURE 11

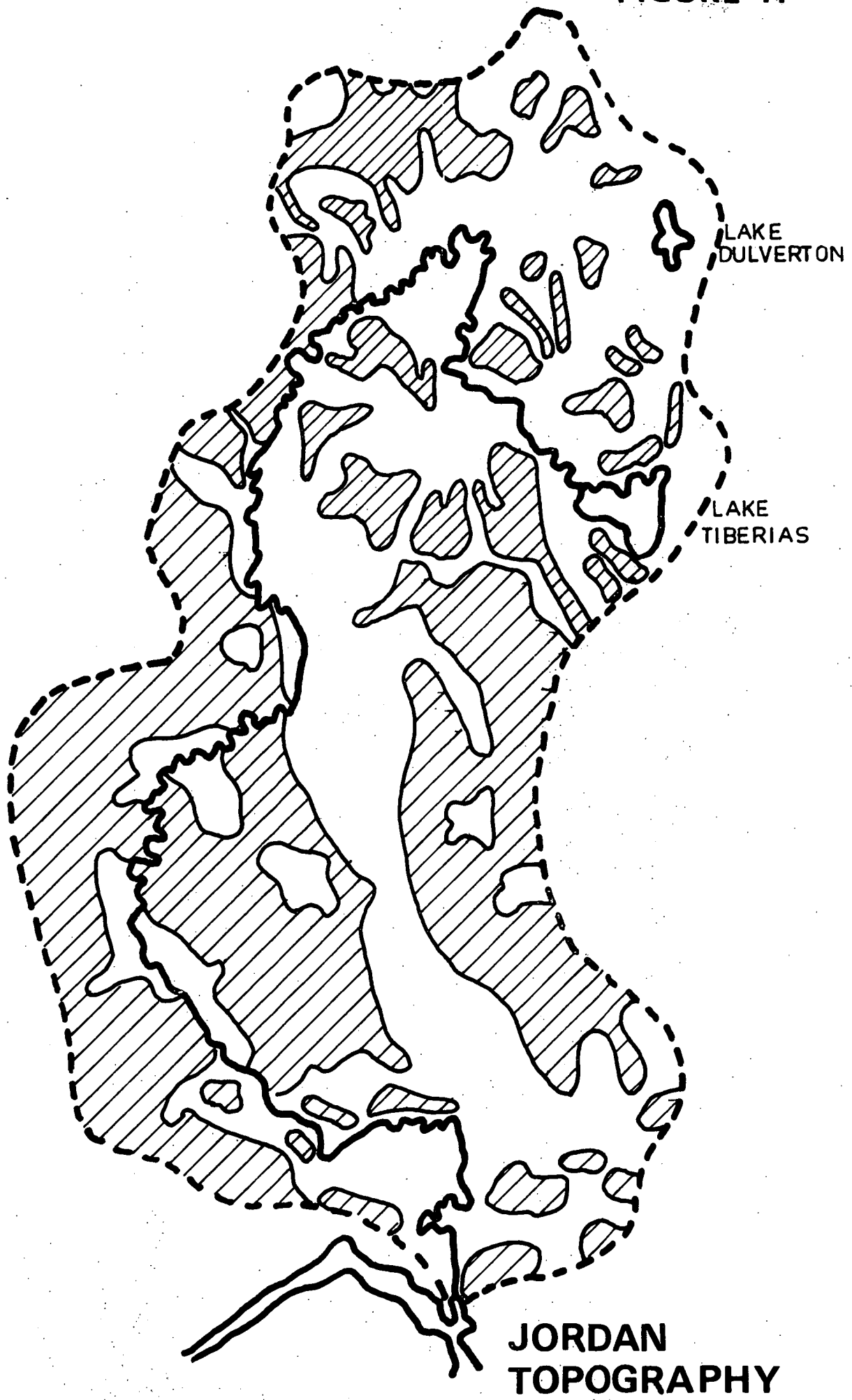
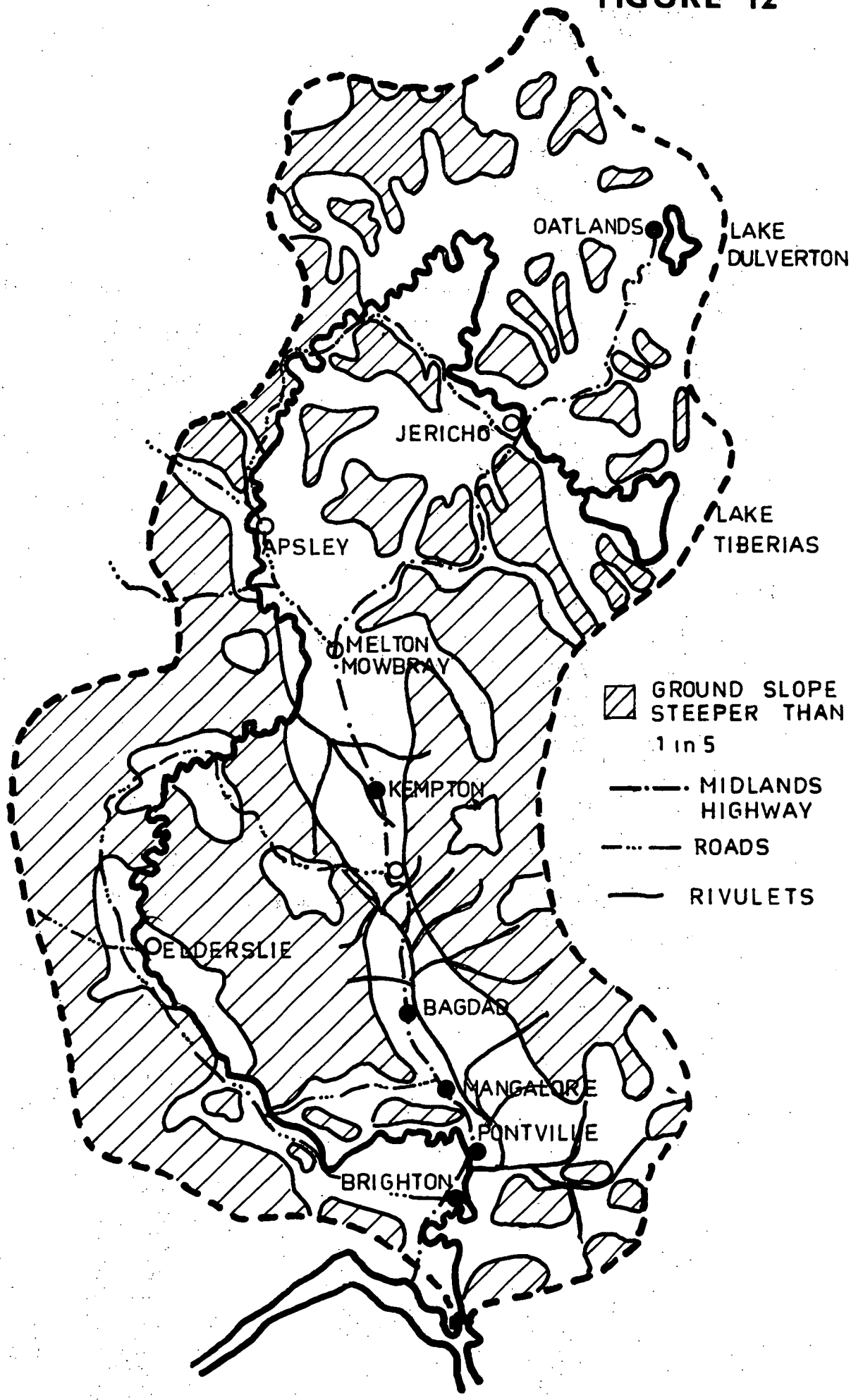

LAKE
DULVERTON
LAKE
TIBERIAS
JORDAN
TOPOGRAPHY
STEEPER THAN 1 in 5

FIGURE 12



JORDAN TOPOGRAPHY - ROADS - RIVULETS

Jericho area, in the valley of the Midlands Highway from Kempton to Pontville and in the Brighton region. The junction of the Bagdad and Strathallan Rivulets at the Pontville Ford should be of particular interest.

1 *NYE, P.B., 1922;*
The underground water resources of the Jericho-Richmond-Bridgewater area;
Underground Water Supply Paper No.2; Tasmania Department of Mines. Government Printer, Hobart.

2 *LEAMAN, D., 1967;*
The Hydrogeology of the Lake Tiberias Region, Midlands Tasmania; Paper No.34, Department of Mines Technical Report No.12.

3 *DAVIES, J.L., 1974;*
Geomorphology and Quaternary Environments; in: WILLIAMS, W.D., (ed.);
Biogeography and Ecology in Tasmania, pp.17-27; Dr. W. Junk, The Hague.

4 *NYE, 1922; op.cit. pp.48-9.*

5 *LEAMAN, 1967; op.cit.*

6 *Ibid.*

7 *STEANE, J.D., 1967;*
Water Resources of the River Jordan, pp.21-22; Tasmanian Water Resources Survey, Third Report; Rivers and Water Supply Commission, Hobart.

8 *Ibid., pp.23-4.*

9 *Ibid.*

10 *NYE, 1922; op.cit. pp.12-13.*

11 *Tasmanian Department of Mines, 1975;*
Geological Atlas, Oatlands Region; Sheet SK55-6, 1:250,000 Series.

12 *STEVENSON, P.C., 1967;*
General considerations and summary of the six Jordan River dam sites mapped geologically by the Department of Mines March-June 1967;
Paper No.25, Technical Reports No.12; Tasmania Department of Mines.

13 *NYE, 1922; op.cit., p.52.*

14 *Ibid., pp.86-88.*

15 *DIMMOCK, G.M., 1957;*
Reconnaissance Soil Map of Tasmania, sheet 75 - Brighton;
CSIRO Division of Soils Report 2/57.

16 *COWIE, J.D., 1959;*
Reconnaissance Soil Map of Tasmania, sheet 68 - Oatlands;
CSIRO Division of Soils Report 4/59.

17 *COWIE, J.D., 1961;*
The Soils of the Oatlands Rectangle;
CSIRO Division of Soils Report 12/60.

18 *JENSEN, H.I., 1914;*
The Soils of New South Wales;
Government Printer, Sydney.

19 *PRESCOTT, J.A. 1944;*
A Soil Map of Australia;
CSIRO Bulletin No.177.

20 *STEPHENS, C.G., 1973;*
A Manual of Australian Soils;
CSIRO, Melbourne.

21 *DIMMOCK, 1957; op.cit.*

22 *COWIE, 1961; op.cit.*

23 *DIMMOCK, 1957; op.cit.*

24 *NYE, 1922; op.cit. p.87.*

25 *Bureau of Meteorology, 1977;*
Climate of Tasmania; in:
MACLAINE, D.J. (ed.);
Tasmanian Year Book No.11:1977, pp.52-64;
Australian Bureau of Statistics, Hobart Office, Government Printer Tasmania.

26 *SOURCE: BUREAU OF METEOROLOGY:*
Average Annual Rainfall Statistics (photostat sheet).

27 *NYE. 1922; op.cit. pp.26-7.*

28 *BUREAU OF METEOROLOGY, 1977; op.cit.*

29 *Ibid.*

30 *STEANE, J.D., 1967, op.cit. p.14.*

31 *PRESCOTT, J.A., 1949;*
A climatic index for the leaching factor in soil formation;
J. Soil Sc. 1, pp.9-19.

32 *PRESCOTT, J.A., COLLINS, J.A., SHIRPURKAR, G.R., 1952;*
The comparative climatology of Australia and Argentine;
Geog. Rev.: 42, pp.118-133.

33 *LOVEDAY, J.A., 1957;*
The soils of the Sorell-Carlton-Copping Area, South East Tasmania, with special reference to the soils formed on Basalt;
Soils Publ. No.8, C.S.I.R.O.

34 *NYE, 1922; op.cit. p.29.*

35 *LOVEDAY, 1957; op.cit. p.19.*

36 *JACKSON, W.D., 1965;*
Vegetation; in:
DAVIES, J.L. (ed.);
Atlas of Tasmania, p.30;
Lands and Surveys Department, Hobart.

37 *LOVEDAY, 1957; op.cit. p.19.*

38 *JACKSON, 1965; op.cit. p.30.*

39 *MACGREGOR, D.R., 1957;*
Some observations on the geographical significance of slopes;
Geography, 42:167-173

40 *OGLESBY, C., HEWES, L., 1954;*
Highway Engineering, p.256;
Wiley International Publ., New York.

CHAPTER 3

MAN'S USE OF THE RIVER BASIN

This chapter examines the use to which man has put the river basin as reflected by the human and animal populations and their distribution. We anticipated that the physical environment of the basin would have a significant influence on Man's activities and having examined that environment we are now able to look at Man complete in the environmental setting of Man, Microbe and River. Population data on man and animals has been used to calculate the numbers of faecal bacteria and their distribution in the basin. Since man creates artificial areas for legislative purposes and then collects statistics in terms of those areas, we look first at this subdivision of the basin.

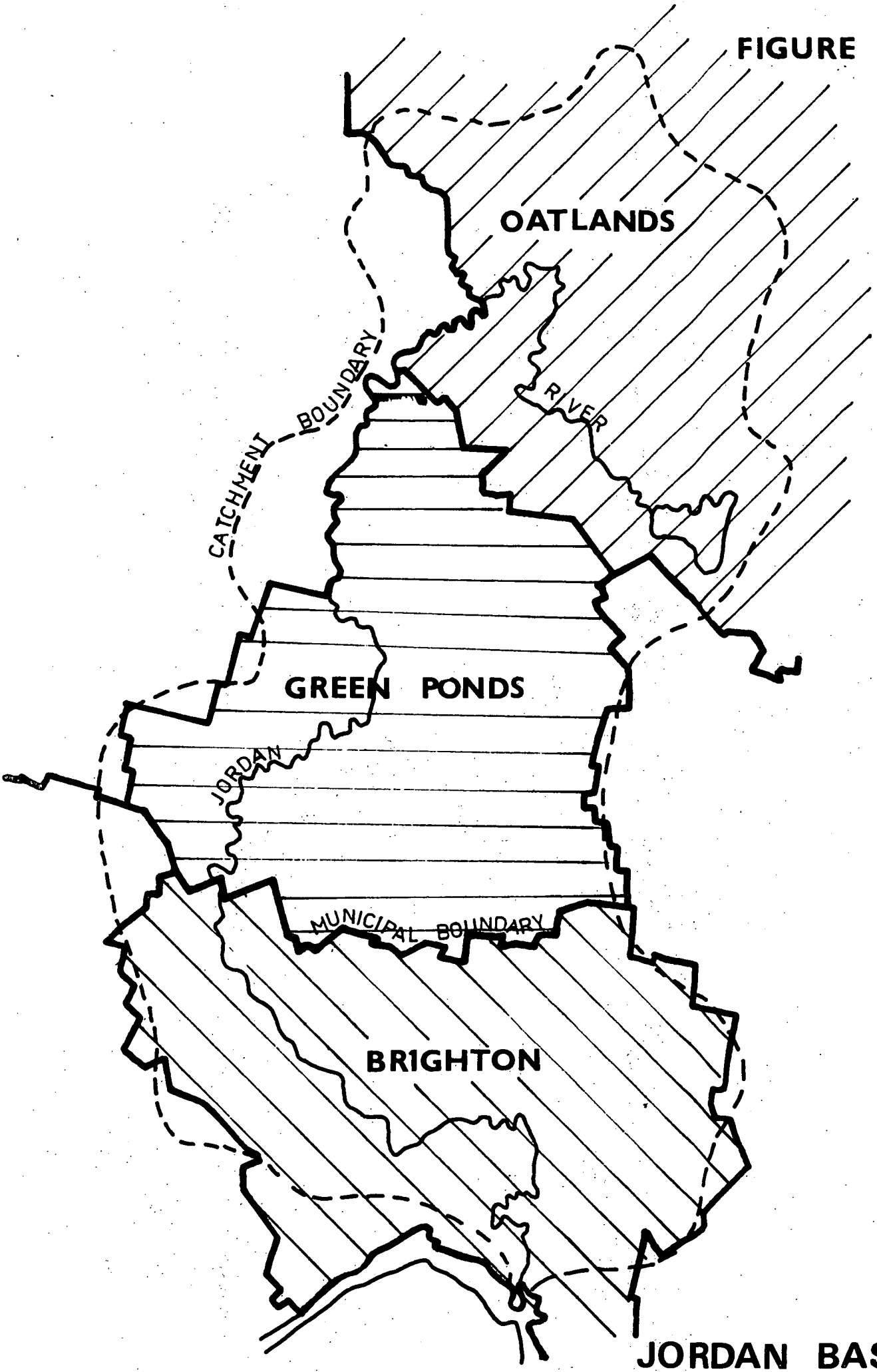
MAN'S SUBDIVISION OF THE RIVER BASIN

Figure 13 shows the basic division of the basin into Municipalities. We have taken the whole of the Municipalities of Brighton and Green Ponds as being contained within the catchment. Statistics[1] show the area of these Municipalities to be 44,100 hectares and 41,600 hectares respectively. Oatlands, which is only partially within the catchment, has an area of 154,000 hectares. Since the area of the river basin is 136,000 hectares[2] it is readily calculated that 33% of the Municipality of Oatlands lies within the catchment. Since no other basis is available at this time, we have used this percentage in this Study as a basis of proportioning Otalands' statistical data to the river basin.

HUMAN POPULATION

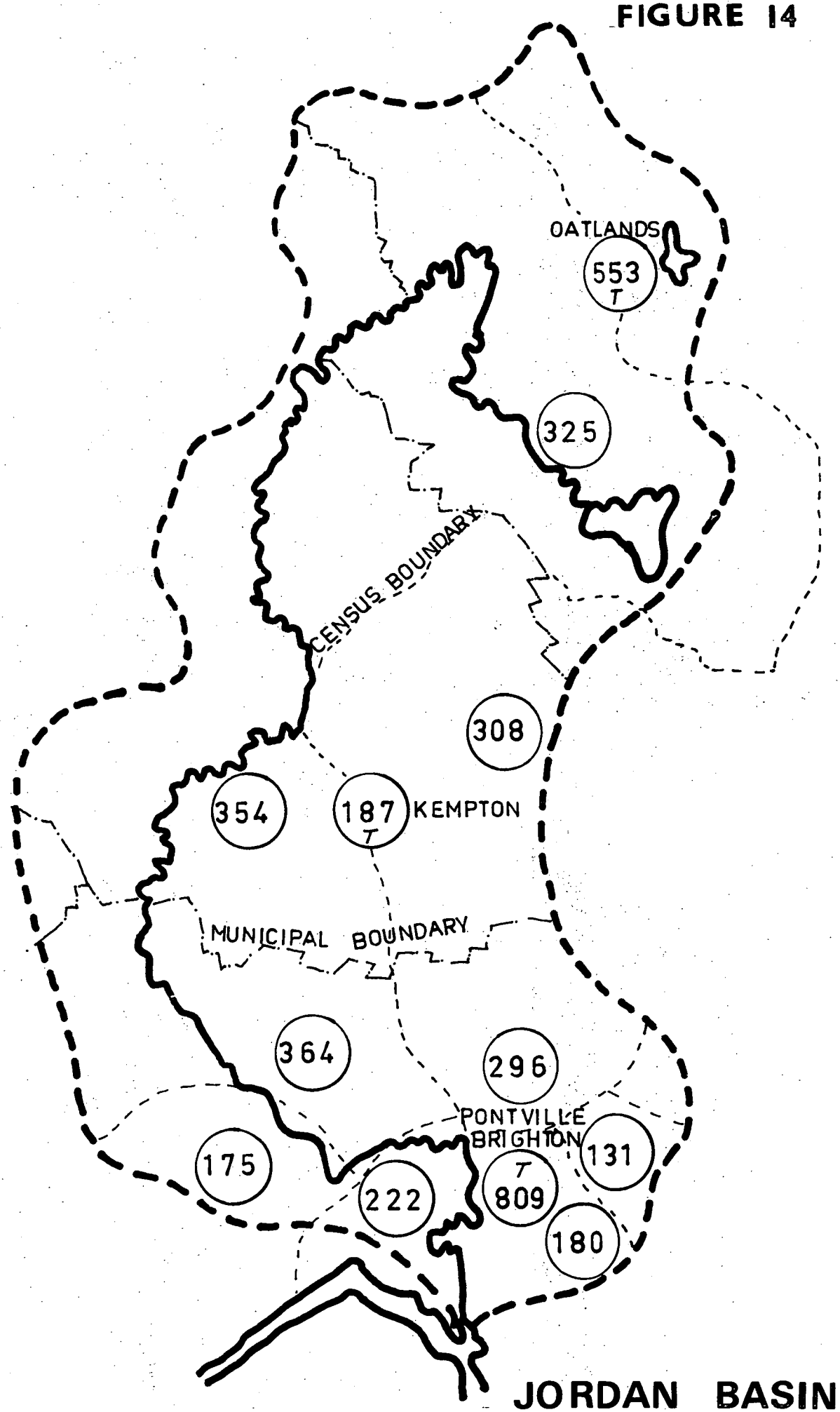
We obtained direct data from the Bureau of Statistics in Hobart. The population is distributed as shown in Figure 14 and Table 4. The figures exclude the urban area

FIGURE 13



JORDAN BASIN
MUNICIPAL BOUNDARIES

FIGURE 14



JORDAN BASIN
HUMAN POPULATION

of the Bridgewater housing development which drains to the Derwent.

TABLE 4

Jordan Basin - Human Population Distribution

Township	No. Persons	Locality	No. Persons
Oatlands	553	Jericho	325
Kempton	187	Kempton	308
Pontville-Brighton	809	Weedon's Hill	354
	1,549	Elderslie	364
		Broadmarsh	175
		Brighton (North)	222
		Brighton (South)	180
		Tea Tree	131
		Bagdad	296
			2,355

Total Population (1976 Census) 3,904

The population trends are given by Table 5.

TABLE 5

Jordan Basin - Population Trends

Year	No. Persons
1954[3]	3,614
1961[4]	3,782
1976[5]	3,904

We used the work of Geldreich[6] to relate man, animal and microbe in the basin. Figure 15 sets out the weight of faeces and the faecal bacteria excreted per 24 hours by man and animal. Using this data Table 6 was calculated for daily average human waste loadings in the catchment.

FIGURE 15

FAECAL INDICATOR ORGANISMS

CONTRIBUTION PER CAPITA PER 24 HOUR

Animal	Wet wt. faeces gm.	Faecal Coliforms x 10^6	Faecal Streptococci x 10^6	Fc/Fs
Man	150	2,000	450	4.4
Duck	336	11,000	18,000	0.6
Sheep	1,130	18,000	43,000	0.4
Chicken	182	240	620	0.4
Cow	23,600	5,400	31,000	0.2
Turkey	448	130	1,300	0.1
Pig	2,700	8,900	230,000	0.04

Ref.: Geldreich, E. Sanitary Significance of Faecal Coliforms in the Environment. U.S. Dept. of Interior. Washington D.C. 1966.

TABLE 6

Jordan Basin - Daily Average Human Waste Loadings

Municipality	No. Persons	Faeces Wt. (tonne per 24 hr.)	No. of Faecal Bacteria	
			Fc x 10^{12}	Fs x 10^{12}
Brighton	2,177	0.33	4.25	0.98
Green Ponds	849	0.13	1.66	0.38
Oatlands	878	0.13	1.71	0.40
	3,904	0.59	7.62	1.76

We calculate that a population of 3,904 humans excretes 0.59 tonne of wet faeces daily and that the faecal bacteria content is 7.62 x 10^{12} coliforms and 1.76 x 10^{12} streptococci. In the case of Oatlands and Brighton Townships, these wastes are treated in lagoons; all others are treated by septic tanks.

ANIMAL POPULATION

The animal population was determined from published statistics.[7] Populations given for Brighton and Green Ponds Municipalities were used in toto with 33% of the figures given for Oatlands Municipality being assigned to the Jordan Basin. Table 7 gives the population distribution and Table 8 the daily average excretion of wet faeces. Table 9 gives the faecal bacteria calculated for these populations from the data of Figure 15.

TABLE 7

Jordan Basin - Animal Populations

Municipality	Cattle & Calves	Sheep & Lambs	Pigs
Brighton	8,528	90,990	447
Green Ponds	4,668	127,026	129
Oatlands[a]	8,416	169,499	156
	21,612	387,515	732

[a] Oatlands statistical figures have been adjusted x 0.33

TABLE 8

Jordan Basin - Daily Average Animal Waste Loadings

Municipality	Faeces (wet wt. tonne per 24 hour)		
	Cattle	Sheep	Pigs
Brighton	128	103	1.2
Green Ponds	70	144	0.3
Oatlands	126	192	0.4
	324	439	1.9

There are then calculated to be approximately 765 tonnes of animal faeces excreted daily in the Jordan Basin.

TABLE 9

Jordan Basin - Daily Average Animal Faecal Bacteria

Municipality	Faecal Bacteria x 10^{12} per 24 hour					
	Cattle		Sheep		Pigs	
	Fc	Fs	Fc	Fs	Fc	Fs
Brighton	29	166	1645	3907	4.0	101
Green Ponds	16	91	2297	5454	1.1	29
Oatlands	29	164	3065	7278	1.4	35
	74	321	7007	16639	6.5	165

There are calculated to be 7000 x 10^{12} faecal coliforms and 17000 x 10^{12} faecal streptococci excreted by animals daily in the Basin.

LAND USE

Visual observation of the Basin in the accessible areas adjacent to roads showed it to be largely savannah used for pastures. The animal population figures of Table 7 supported this observation. As an additional check, statistical data[8] has been determined and is presented in Table 10.

TABLE 10

Jordan Basin - Land Usage (hectare)

Municipality	Total Area	Area for Crops[a]	Sown Pasture Harvested	Sown Pasture
Brighton	44100	1337	793	15387
Green Ponds	41600	585	332	13139
Oatlands	50800	1315	325	19250
	136500	3237	1450	47776

[a] Total crops as defined by A.B.S.

The area under crops is 2.37% of the total area of the Basin; the harvested sown pasture is 1.06% and the sown pasture is 35%, to give a total of 38.43% of the Basin being used for agricultural purposes.

The use of irrigation is shown in Table 11.

TABLE 11

Jordan Basin - Irrigation (hectare)

Municipality	Total Area	Crop Area	Pasture Area	Total Irrigation
Brighton	44100	19	214	233
Green Ponds	41600	1	0	1
Oatlands	50800	0	2	2
	136500	20	216	236

The irrigated area is only 0.17% of the Basin area, and of the total irrigated area of 236 hectares, no less than 233 hectares, or 98.73%, occurs in the Brighton Municipality.

REVIEW

This section has established the broad outline of the interaction between Man and the Jordan. The River Basin has been shown to have low rainfall and high evaporation. The topography and climate impose great constraints upon man, have limited his activities to only 38% of the Basin's area and have determined his areas of location. For most of the Basin the poor soils leave little room for alteration in usage even if additional irrigation is practised. The topography again has influenced the drainage system and in particular has linked with man's activities in the Bagdad and Strathallan Rivulets to give the major drainage in the Basin into the Jordan at the Pontville Ford. It is indicated that if pollution exists in the river system it is most likely to be detected in the River from the Pontville Ford downstream to Herdsman's Cove.

1 *AUSTRALIAN BUREAU OF STATISTICS, TASMANIA, 1976;*
Compendium of Municipal Statistics, 1975;
A.B.S. Hobart.

2 *STEANE, J.D., 1967;*
Water Resources of the River Jordan;
Tasmanian Water Resources Survey, Third Report;
Rivers and Water Supply Commission, Hobart.

3 *Ibid.*

4 *Ibid.*

5 *AUSTRALIAN BUREAU OF STATISTICS, TASMANIA, 1977;*
Population of Tasmania, 1976, Census;
Unpublished Report, A.B.S. Hobart.

6 *GELDREICH, E.E., 1966;*
Sanitary Significance of Faecal Coliforms in the Environment;
U.S. Department of the Interior, Federal Water Pollution Control Administration, Washington, D.C.

7 *AUSTRALIAN BUREAU OF STATISTICS, TASMANIA, 1976;*
Agricultural Industry, 1975-76;
A.B.S. Hobart.

8 *Ibid.*

SECTION C:

MAN, MICROBIOLOGY AND RIVERS

MAN, MICROBIOLOGY AND RIVERS

In this Section, the development of Microbiological techniques as a tool for measuring certain interactions between Man and River is examined; a methodology of sampling chosen and the sampling results given. In Section B we established the physical background for the interactions between Man and River. Now, in this Section, we use that background to determine the criteria applicable to the microbial examination of river waters as potential health hazard to Man. In Section A we stated our intent of examining coliforms, not in isolation, but as part of a total system. Coliforms have been shown to occur in River systems and the development of their use as a tool to indicate possible health hazard in the system is discussed. The development of the faecal coliform test is examined as is the development of the concept of the faecal coliform to faecal streptococci ratio.

This Section is divided into Four Chapters. Chapter Four uses the discussion and findings of Section B to establish the microbiological water quality criteria for determining health hazards. In this establishment, the concepts of Water Quality and of Criteria are examined. Chapter Five is specifically microbiological and traces in detail the development of coliform testing and in particular the development of the faecal coliform test to the current state of the art. We present a review of these tests at the end of Chapter Five. This review is a reference source for the later discussion on Boyer in Section D and is the basis for our conclusions on the need to more rigorously define the definition and significance of faecal coliforms which we discuss in Section D.

Then in Chapter Six we present our choice of testing techniques and use the knowledge gained in Sections A and B and in Chapters 4 and 5 to choose sampling sites.

Chapter Seven concludes the Section with the presentation of Sampling results.

CHAPTER 4

MAN, RIVER AND WATER QUALITY

Section B has shown the Jordan to be in a region of low rainfall and high evaporation. Consequently, water can be expected to be a scarce resource. On checking demands on the water resources we found that no towns use the River for domestic water. Oatlands obtains its water from the Blackman River[1] and the townships from Kempton to Brighton obtain their supply from the Derwent River at Lawitta.[2] The Jordan 'ceases to flow practically every summer'[3] and 'there is far more land suitable for irrigation than can ever be irrigated from the water available.'[4] However the long term average flow of the River is estimated to be in excess of twenty cusecs as measured at the Mauriceton Gauge.[5] The Rivers and Water Supply Commission have investigated six dam sites on the Jordan and favour a dam at Kempton.[6] We have observed children playing in the River at the Pontville Ford, where there is a large shallow pool at the confluence with the Bagdad and Strathallan Rivulets, and at Herdsman's Cove, which is a Conservation Area.[7] We have observed numerous pools adjacent to bridges over the River in various locations along its length downstream from Rutland (Figure 10) and have seen fishermen using these pools. The River system is indicated as being used for irrigation and for recreation. Each of these uses has its own special requirements involving the relationship between man, microbe and river. The interactions within the relationship determine the suitability of the river water for its intended use. The suitability of the water for its use is determined by its quality.

WATER QUALITY

Water quality is difficult to define. It is a function of the use to which the water is to be put, rather than an intrinsic property of water itself. The doubly distilled

water necessary for laboratory work is unpalatable to the person who tries to drink it, while the treated effluent from a township may be acceptable for use in a paper mill, although rejected out of hand by a food processor.

As the use of water varies, so will the requirements (or criteria) by which the water is judged to be of good quality.[8] Most of these uses are dependent upon there being only very low levels of unwanted matter (pollutants) in the water, rather than requiring the presence of any specific substance - oxygen is an important exception. Because of this, water quality is often more easily defined in terms of allowable levels of pollutants.

The Senate Select Committee on Water Pollution[9] defined water pollution as: 'an impairment of water function which has, or may have, an effect on subsequent water use.'

From this it follows that water quality can be classed as acceptable if no deleterious effects on further water use occur. It should be noted too, that water use does not involve human uses only - although this study was mainly concerned with these - but also recreation and aesthetics: fish, other aquatic life and wildlife; agricultural uses for livestock and irrigation, and industrial uses.[10] To decide whether water quality is acceptable for a particular use we must have a reliable criteria by which we can judge it.

CRITERIA

Water quality criteria have been defined as: ' a scientific requirement on which a decision may be based concerning the suitability of water quality to support a designated use.'[11] This definition is similar to that of McKee and Wolf,[12] who caution that criteria are only the means by which a judgement may be made, and should not be regarded as having any intrinsic authority. Standards, on the other hand, although

based on criteria, have legally enforceable authority, and must not be confused with criteria.

Hart has produced a book of recommendations for Australian water quality criteria.[13] Although titled A Compilation of Australian Water Quality Criteria, it is based mainly on overseas research (this is true for the microbiological criteria, it may not be true for other areas in which we were not interested) because of the limited research that has been conducted within Australia. From these recommended criteria it would be possible to derive Australian Standards (the Senate Select Committee on Water Pollution was told in 1970 there were no Australian standards for water quality,[14] and, as far as we know, there are still none). Without the necessary research in local conditions to verify the criteria, however, it is possible that any standards so derived could be successfully challenged in court.

The Tasmanian Environment Protection (Water Pollution) Regulations 1974 do not set bacteriological criteria or standards for the uses of receiving waters, only emission standards for inland waters and bays and estuarine waters.[15] This use of emission standards, rather than standards or criteria for receiving waters is unusual.[16] It also meant that, to evaluate the possibility of health hazards in the two rivers studied, we had to decide on what criteria we should base our judgements, rather than use pre-existing standards, and to classify the uses of the rivers in such a way that we could use available criteria rather than formulating our own.

Use of the Rivers.

To decide what criteria to apply, we studied the uses made of the river by humans, since we were mainly interested in possible hazards to human health.

Neither the townships nor most of the rural holdings along the Jordan River take their drinking water from the

river. The lowest major take off point for drinking water on the Derwent is at Lawitta, the most upstream of our sampling sites on that river. There seemed little point in applying criteria for drinking waters, as little use was made of the rivers as sources of potable waters.

Water seems to hold an intrinsic fascination for children. Even during the months April to September, which is when we were taking samples, it was not uncommon to see children playing in the rivers, and even (rarely) swimming. Pontville Ford and Herdsman's Cove were the favoured sites on the Jordan; on the Derwent: from or opposite the New Norfolk Rowing Club launching ramp. Fishing appeared to be a favourite past-time of children near New Norfolk, especially at the water-ski club just downstream and across the river from the New Norfolk sewage treatment works.

Water skiing was popular on the Derwent from New Norfolk to Bridgewater, except in the depths of winter. This was mainly a sport practised by adults, as was power boating.

From our observations we concluded that the most probable victims of any potential micrbiological health hazard would be children. Not only do they appear to use the rivers more than do adults, but also they come into contact with the water more intimately than do the adults (with the exception of water skiers). For this reason we considered the most applicable water quality criteria to be those concerned with the assessment of microbiological hazards of bathing or primary body contact recreational uses. (Primary body contact occurs when prolonged and intimate contact with the water - swimming, washing, paddling or waterskiing - leads to the possibility of ingesting enough water for infections to occur in contaminated water.[17])

Applicable Criteria.

The criteria applicable to health hazard are based on microbiological testing. We have, in this Study, chosen applicable criteria, as determined by various authorities, and then examined the microbiological setting for that criteria as being the most convenient method of approach.

Hart has suggested that for recreational waters where bathing occurs, 50 or less faecal coliforms/100 ml. is satisfactory (during the recreational season); between 50 and 200 faecal colifroms/100 ml. is considered slight pollution. If 200 faecal coliforms/100 ml. is approached or exceeded regularly during the recreational season, he suggests that action - surveying for sanitary hazards, testing for pathogens - should be taken to assess the health risks.[18]

In the U.S.A. the National Technical Advisory Committee on Water Quality Criteria (whose recommendations were later adopted by EPA) recommended that, in primary body contact recreational waters, the logarithmic mean should not exceed 200 faecal coliforms/100 ml., and that the faecal coliform counts should exceed 400/100 ml. on no more than 10% of occasions tested.[19]

A recent comparison of several bacteriological standards or criteria suggests that a logarithmic mean of 200 faecal coliforms/100 ml. has found favour with many authorities.[20]

Tasmanian Water Pollution Regulations.

Unlike the water quality criteria discussed above, the Tasmanian environmental regulations are emission standards and are written in terms of absolute maxima. 'The faecal coliforms in the emission shall not exceed 200 per 100 millilitres'[21] (for inland waters such as the Jordan to

Herdsman's Cove, and the Derwent down as far as the New Norfolk sewage treatment plant), or 1000/100 ml. for bays and estuarine waters[22] (from the sewage treatment plant onwards down the Derwent).

Several criticisms can be levelled at the emission standards approach used in Tasmania. Three that have been suggested[23] are: that each receiving water is a separate case and should be treated as such; that the volume of the effluent should be taken into consideration, not just the concentration (ten times the quantity of effluent at the same concentration is likely to ~~be more polluting~~ pollute more); and that emission controls ignore the ability of diffusers to dilute the effluent. At present a bather in estuarine waters where there is poor mixing between effluent and water may be swimming in waters containing up to 1000 faecal coliforms/100 ml., if a simple pipeline is used to release the effluent. If a diffuser were fitted an initial dilution below 100 faecal coliforms/100 ml. may readily be achieved.

Another criticism that can be made is that, by using absolute maxima, no allowance is made for error or sudden peaks in loading which briefly push the emitted effluent above the legal limit. The implication is that if logarithmic means are used, this momentary aberration will vanish. A single release of say 10^6 faecal coliforms/100 ml. would be submerged if, in ten tests, the other nine tests gave readings of 100 fc/100 ml. If this single reading were during the recreational season, near a bathing beach however, it could have considerable public health significance and should warrant action.

Our Choice of Criteria.

In the absence of criteria as discussed above, we had to choose our own. Our choice was based upon the major observed water usage of recreation and again, as discussed above, both the U.S.A. National Technical Advisory Committee and Hart give recreational criteria.

The U.S.A. criteria are based upon three major epidermiological surveys which concluded that detectable health risks occurred at a faecal coliform level of about 400 faecal coliforms/100 ml. and that viruses could be detected at these levels with enough frequency to be a health risk.[24] The U.S.A. Committee considered, though, that local surveys should be done when setting regional criteria.

Hart's Australian Criteria are based on these U.S.A. surveys and on later American studies which ~~showed~~ suggested a marked increase in the likelihood of detecting Salmonella and viruses in water when the faecal coliform count was greater than 200/100 ml.[25] Since the Australian recommended criteria are based on more recent studies of the U.S.A. criteria, we chose them.

Limitations on our Choice.

Our chosen criteria are based upon primary body contact (bathing) recreational use. Our sampling was carried out during the winter (non recreational) season. It is likely that the summer season not only sees more recreational use but also that the coliform counts observed by us will change. However, as no floods occurred during our sampling programme (which might markedly elevate the level of faecal coliforms[26]) and, as our results suggest that faecal coliforms in the Derwent rise during the summer months when the river flow is reduced, we feel justified in using the criteria for our preliminary look at faecal coliform counts as health hazards.

1 *STEANE, J.D., 1967;*
Water Resources of the River Jordan;
Tasmanian Water Resources Survey, Third Report;
Rivers and Water Supply Commission, Hobart.

2 *METROPOLITAN WATER BOARD, 1963;*
1st Annual Report 1963;
Tasmanian Parliamentary Papers, No.75 of 1963.

3 *STEANE, 1967; op.cit. p.6.*

4 *Ibid.*

5 *Ibid.*

6 *Ibid.*

7 *PROCLAMATION BY GOVERNOR, 1941;*
Under Animals and Birds Protection Act 1928;
Tas. Gov. Gazette, 28th February, 1941; p.547.

8 *NCWQ, 1968;*
Report of the National Technical Advisory Committee on Water Quality Crieria, p.vii;
Federal Water Pollution Control Administration, U.S. Department of the Interior, Washington, D.C.

9 *SENATE SELECT COMMITTEE ON WATER POLLUTION, 1970;*
Water Pollution in Australia, p.11;
Commonwealth Government Printing Office, Canberra.

10 *NCWQ, 1968; op.cit., p.vii.*

11 *Ibid.*

12 *McKEE, J.E., and WOLF, H.W., (eds.), 1971;*
Water Quality Crieria, 2nd Revised Edition;
California State Water Resources Control Board Publication 3-A.

13 *HART, B.T., 1974;*
A Compilation of Australian Water Quality Criteria;
Australian Water Resources Council Technical Paper No.7;
Australian Government Publishing Service, Canberra.

14 *SENATE SELECT COMMITTEE, 1970; op.cit. p.82.*

15 *ENVIRONMENT PROTECTION (WATER POLLUTION) REGULATIONS, 1974;*
Government Printer. Tasmania.

16 *DR. D.A. RITZ: personal communication.*

17 *NCWQ, 1968; op.cit., p.11.*

18 *HART, 9174; op.cit., p.165.*

19 *NCWQ, 1968; op.cit., p.12.*

20 *SCOTT and FURPHY, 1977;*
Southern Metropolitan Sewage Study, p.43, table 3.3;
Government Printer, Hobart.

21 *ENVIRONMENT PROTECTION (WATER POLLUTION) REGULATIONS, 1974; op.cit.*

22 *Ibid., p.6.*

[23] *SCOTT AND FURPHY, 1977; op.cit., p.40.*

[24] *NCWQ, 1968; op.cit., p.12.*

[25] *HART, 1974; op.cit., pp. 162-5.*

[26] *SENATE SELECT COMMITTEE, 1970; op.cit. p.34.*

CHAPTER 5

MAN AND MICROBIOLOGY

In the previous Chapter we established microbiological criteria for this Study. This Chapter now looks in detail at the interaction of man and microbe and examines the work which has led to the criteria discussed in the previous ~~Cahpter~~ Chapter. The early demonstration of microbial disease transmission to man through water contact has been followed by protracted research to determine when and if health hazards exist in water and when they do not. This Chapter follows the development of the tests to distinguish coliforms of specific faecal origin. The concept of faecal coliform to faecal streptococci ratio, its significance and its limitations ~~is~~ a/e discussed.

MAN'S HEALTH AND WATER CONTACT

Water is a vehicle of transmission for many infectious diseases of animals and men.[1] Amongst the water-borne and water-associated† communicable diseases are cholera, typhoid and paratyphoid fevers, bacillary and amoebic dysentries, bacterial and viral gastroenteritis, leptospirosis, infectious hepatitis, and poliomyelitis.[2]

The pathogens causing these diseases emanate in particular from the gut of man and warm-blooded animals. Entry to transmitting waters may be via direct discharge of man or animal wastes or indirectly via waste effluents, farmlands and animal feed lots and contaminated soils or vegetation.[3] Once in the water, pathogens enter the host by either primary or secondary contact with the host.

† *"Water-borne" implies that water is the principle means of spread of the disease (for instance schistosomiasis); "water-associated" suggests that water is only one of many means of spread (as with infectious hepatitis).*

Primary contact involves direct exposure of the host to the pathogen through drinking, or bathing in, contaminated waters.

Secondary contact is indirect: the contaminated water has been used for the irrigation of crops; for food processing or cooking; or for recreational use,[4] and the pathogens are spread during these processes.

DETECTION OF PATHOGENS

The number of pathogens needed to cause disease is, at present, a matter for conjecture; and the epidemiological evidence is both slight and conflicting.[5,6] Additionally, direct testing for pathogens in water is ~~difficult to impossible~~ extremely difficult in some cases (infectious hepatitis and many other viruses) or nonstandardized for those organisms that can be detected, such as typhoid and paratyphoid (Salmonella); and are too complex and time-consuming for routine use.[7]

Microbiological Testing of Waters - Indicator Organisms.

The basic premise in the microbiological testing of waters is that most pathogens enter the water from the excreta of man and animals, and infect man through his contact with these pathogen-carrying waters.[8] Therefore, if faeces can be detected in water, there is a possibility that pathogens (which are difficult to detect) will be present in the water.

Non-pathogenic bacteria are present in faeces in large numbers, and certain groups of bacteria have been found to be consistently associated with faeces. These bacteria are relatively easy to detect. Their presence is said to indicate faecal contamination of the water; and so, they are called indicator organisms.

History of Indicator Organisms.

In 1880 Von Fritsch described two bacteria, Klebsiella pneumoniae and K. rhinoscleromatis, which he called "organisms characteristic of human faecal contamination";[9] and, in 1885 Escherich identified Bacillus coli (now Escherichia coli) as a component of faeces.[10] Because the family of bacteria - the Enterobacteriaceae - of which E. coli, the Klebsiellae and the Salmonellae are all members, is both large and diverse,[11] much effort has been put into defining the subgroupings within it; and their practical significance.

THE COLIFORMS

One of these subgroups - the coliforms - has become, for historical reasons, the main group of indicator organisms in the examination of water.[12,13] The definition of this subgroup of bacteria differs markedly in the British and the U.S.A. bacteriological methods manuals.[14,15] We adopted the American definition in this project, because the research into the significance of the faecal coliform to faecal streptococci ratio has been conducted mainly by Americans, using the American manual (Standard Methods 14) as the technical reference. The coliform group is there defined:

"The coliform group comprises all of the aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C."[16]

The definition covers a "large and heterogenous group of gram-negative rods resembling, to some extent, Escherichia coli."[17] The distinction between the bacterial total coliform group and a specific member, E. coli, is significant. The terms E. coli and faecal coliforms are often used interchangeably.[18] Whilst E. coli is a true faecal coliform[19] and does not normally multiply outside the intestine, the

other coliforms as defined need not necessarily be faecal. Although they may occur in faeces (in lower numbers than does E. coli[20]) the presence of coliforms in water does not necessarily mean that faecal contamination has occurred.[21]

FAECAL COLIFORMS

The separation of coliforms into those of faecal origin and those of non-faecal origin was first proposed by Eijkman in 1904.[22] He observed that coliforms from the gut of warm blooded animals produced gas at 46^{C}, whereas non-faecal coliforms would not.

Geldreich has derived from Eijkman's observations, and those of other workers, including himself, a set of guide-lines which may be used to separate faecal and non-faecal coliforms.

"1. The most acceptable temperature of incubation for separation of the fecal coliform group is 44.5^{C} in a water bath.

2. A small percentage of the fecal coliform strains will be excluded and an equal percentage of non-fecal coliforms will be included.

3. E.C. medium, described by Perry and Hanja, will give the most rapid results, as it requires only 24 hour incubation.

4. The test can be used only as a confirmatory procedure from coliform cultures growing on a non selective medium.

5. In the evaluation of results, all coliforms from the feces of warm-blooded animals must be considered as fecal coliform strains, and all cultures isolated from unpolluted soils must be considered as non-fecal coliform strains."[23]

Detection of Faecal Coliforms.

In examining samples of water for the presence of faecal coliforms, the first step is to test for "total coliforms". If, after incubation in lactose or lauryl tryptose broth at 35^{C} for 48 hours, gas is produced, these coliforms are presumed to be present in the samples in the tubes where gas was produced. (For fuller details see Chapter 6). These samples are then inoculated into E.C. medium and incubated in a water-bath at 44.5^{C}. Those tubes in which gas is produced within 24 hours by definition contain faecal coliforms. The other tubes do not.

This method of detecting faecal coliforms has been adopted (with modifications) by the American Public Health Association (APHA) in the manual: Standard Methods for the Examination of Water and Wastewater, 14^{th} Edition,[24] which was used as the major technical reference in our investigation.

Reliability of the Technique.

In developing the concepts outlined above, Geldreich demonstrated that 96.4% of the total coliforms in human faeces were faecal coliforms, and that 93.0-98.7% of the total coliforms excreted by warm-blooded animals were faecal coliforms.[25] In a further study he showed that fresh-water fish do not have a permanent flora of coliforms in their intestines;[26] if any coliforms are found, it is related directly to contamination of the aquatic environment.[27]

Previously it had been shown that the few faecal coliforms detectable on vegetation had been derived from animal manure, or night soil; or from contact with contaminated insect pollinators, or agricultural pests.[28]

Geldreich concludes[29] "faecal coliform organisms may be considered indicators of recent faecal pollution". "Therefore

it is necessary to consider all faecal coliform organisms as indicative of dangerous contamination".

OTHER INDICATOR ORGANISMS

Faecal coliforms are, however, only one of three groups of bacteria commonly used for indicating faecal contamination of water.[30] The other two groups are faecal streptococci and Clostridium perfringens. Faecal streptococci are a broad group of small spherical bacteria normally found in the faeces of warm-blooded animals (including man), and which are identified by their ability to grow in media containing sodium azide.[31] Clostridium perfringens (formerly C.welchii[32] - the gas-gangrene organism) is a gram-positive spore-forming anaerobic rod.

Both faecal streptococci and C. perfringens survive longer in water than does E.coli[33,34], so may be used to detect pollution more distant in time or place from the source of the contamination than can faecal coliforms; but neither can be used by itself for making an estimate of when the pollution occurred.

As C. perfringens is not recommended as an indicator organism by the technical manual we were using[35] (though it is used apparently by British workers[36]), and because its spores may persist in a viable state for years - making its presence a poor indicator of the presence of pathogens - we did not consider it further for use in this project.

Faecal Streptococci and Their Use.

There is little evidence that the numbers of faecal coliforms correlate well with those of viruses, and some evidence that, in partially chlorinated waters, faecal coliforms may be suppressed while viruses are less affected by the chlorine.[37] Consequently there is a danger

that water free of faecal coliforms may still cause viral diseases, e.g. poliomyelitis and infectious hepatitis.

Cohen and Shuval have shown that the disappearance rate of faecal streptococci from water more closely parallels that of viruses than does the die-away of faecal coliforms.[38] Hart stated that "faecal streptococci are more resistant to both natural and man made purification processes" than are the coliform or faecal coliform organisms.[39]

Because of these properties, streptococci would seem a desirable indicator for use along with faecal coliforms.

THE FC:FS RATIO

There is another reason for the examination of waters for both faecal coliforms and faecal streptococci.

In 1969 it was suggested by Geldreich and Kenner that the ratio of faecal coliforms to faecal streptococci could be used to determine whether contamination of waters was being caused by animal or human wastes.[40] The intestinal flora of man and other animals exhibit a difference in the numbers of faecal coliforms and faecal streptococci. Geldreich and Kenner reported that the faecal coliform to faecal streptococci ratio (usually abbreviated to fc:fs) was greater than 4 (is to 1) in man, and less than 0.7 in other warm-blooded animals. For fresh contamination (contamination of less than 24 hours duration prior to examination) the fc:fs ratio could be used to distinguish between human and animal faecal pollution of water.

Common Fc:Fs Ratios and their Significance.

Geldreich has calculated the fc:fs ratios for various farm animals as well as for man. For all the common farm animals the ratio is less than 0.7 (duck 0.6; sheep 0.4;

chicken 0.4; cow 0.2; turkey 0.1; pig 0.04), while for man it is 4.4.[41] He suggests that if the fc:fs ratio is greater than or equal to 4.0 the pollution is probably human, between 4.0 and 2.0 the wastes are mainly of human origin; between 1.0 and 0.7 animal wastes predominate in mixed pollution, and with fc:fs of less than 0.7 the wastes are probably animal in origin.

Fc:Fs Limitations.

There are constraints on the interpretation of the fc:fs ratio.[42] The pH must be between 4 and 9; the fc and fs must be made on the same sample; the sample should be taken no further downstream from the source of the pollution than the river will flow in 24 hours; and only the faecal coliform count (not the total coliform count) may be used to calculate the fc:fs ratio.

The pH restrictions parallel those within which the organisms are viable; the 24 hour limit was suggested because faecal coliforms die away faster than do faecal streptococci, thereby altering the fc:fs ratio.[43]

McFeters et al have suggested that this differential die-away rate limits the use of the fc:fs ratio to within a short time after contamination,[44] but Feachem disagrees,[45] and has used McFeters' own data to show that the differential die-away can itself further define the source of pollution. With human wastes the fc:fs ratio falls with time (and/or distance), while for contamination by animal wastes the fc:fs ratio tends to rise with time (due to the presence of some short lived ~~strains~~ types of faecal streptococci).[46]

BACTERIAL INTERACTIONS WITH THE ENVIRONMENT

Bacteria, like all other living organisms, are influenced by their environment. This influence is reflected, not

in the size of the individual organism as with many of the more complex organisms - but in the rate of reproduction. This is determined by environmental factors; nutrients, pH, temperature, aeration, salt concentrations, and perhaps light. These factors form the growth parameters of the organisms. They are related to the survival parameters which we consider later.

Nutrients.

The nutritional requirements of bacteria are basically similar to those of higher organisms, which from an evolutionary view, is not unexpected. Carbon, nitrogen, hydrogen and oxygen are required in relatively large amounts, and phosphorus and sulphur in somewhat smaller quantities. Many other elements are essential, but generally only in small or trace amounts.

pH.

Most organisms have an optimum pH which is fairly close to neutral, but many can exist over a range of pH. Faecal coliforms and faecal streptococci are not severely affected by a pH range of between 4 and 9.

Temperature.

Similarly, each bacterial species only grows within a certain temperature range. The optimum temperature for enteric bacteria is about 37^{C}, about that of their natural habitat, the intestines of warm-blooded animals. These bacteria have a range of about $25\text{-}40^{C}$, along with many saprophytes of soil and water; they are said to be mesophilic bacteria. Streptoccus faecalis has a viable range of $10\text{-}45^{C}$, about the same as E.coli.

Oxygen Requirements.

Some bacteria (the obligate aerobes), can only grow in the presence of oxygen; while others (the obligate

anaerobes), can only grow in the absence of oxygen. Many bacteria are relatively indifferent to the presence of free oxygen, and are called faculative anaerobes.[53] E. coli and the faecal streptococci are included in this group.

Salinity.

Salinity has little effect on most bacteria below 3000 mg/l of chloride. Faecal streptococci grow in up to 6.5% (65,000 mg/kg) salinity,[54] E. coli on 6% (60,000 mg/kg) salinity.[55] As this is far greater than the salinity of sea water;[56] we did not expect to find salinity affecting our results.

Survival Parameters.

Waters receiving faecal bacteria are generally stable aquatic ecosystems in which a balance between the different communities of micro-organisms has been achieved.[57] The faecal micro-organisms are foreign to the receiving water ecosystem and unbalance it. Equilibrium is restored by portion of the native microflora reacting to the perturbation in the classic predator-prey relationship.[58] This natural reaction causes mortality of the faecal micro-organisms additional to that of environmental stress due to unsuitable environmental conditions. From the discussion above on environmental requirements, temperature difference between man and animal gut and receiving waters can be expected by itself to cause considerable mortality. (Animal gut 37°C; Receiving waters of Jordan/Derwent 7-20°C).

In addition to these biological and chemical survival parameters, the biophysical influences of sedimentation, biological flocculation and precipitation are added.[59]

The removal of the faecal micro-organisms is usually assured. What is unknown, and indeed constantly changing,

is the rate of [redacted] mortality. The measurement of the total effect of the survival parameters of food supply, environmental stress and predation is complicated by the effects of flow rate and dilution in the receiving waters and reliance has been placed on in situ investigations. These investigations[60] have shown that the mortality of enteric bacteria is more rapid in heavily polluted streams than in clean streams; in warm weather than in cold weather; in shallow, turbulent streams than in deep, sluggish bodies of water.

There also appears to be some parameter involving stream size. Investigations on a small stream and a large stream[61] gave the following results:-

Flow Time (hr.)		10	20	100
Coliform Mortality%	Small Stream	97.5	97.9	98.9
	Large Stream	36	59	98.7

REVIEW

Faecal coliforms are used to indicate the presence of faeces in water, and the possible presence of enteric pathogens from warm-blooded animals including man. The use of faecal coliforms for this purpose is based on certain assumptions:-

a) Rivers and other natural waters do not usually contain faecal coliforms unless the faeces of man or warm-blooded animals have entered the waters.

b) The numbers of faecal coliforms are related to the probability of the presence of pathogens and their numbers.

c) Faecal coliforms normally occur only in faeces.

d) Faecal coliforms can be distinguished from non-faecal coliforms.

It has been suggested that the faecal coliforms of man can be distinguished from

careful interpretation of

those of warm-blooded animals by the faecal coliform to faecal streptococci ratio. In man the ratio is greater than 4.0; in animals the ratio is less than 0.7.

1 *LIPTAK, B.G., (ed.), 1974;*
Environmental Engineers' Handbook, Volume 1: Water Pollution, pp.282-4;
Chilton Book Company, Radnor, Pennsylvania.

2 *McKEE, J. and WOLF, H., 1963;*
Water Quality Criteria, pp.132-3;
The Resources Agency of California, State Water Quality Control Board Publication No.3-A.

3 *GELDREICH, E.E., 1966;*
Sanitary Significance of Faecal Coliforms in the Environment, p.1;
Federal Water Pollution Control Administration, U.S. Department of the Interior, Washington, D.C.

4 *NCWQ, 1968;*
Report of the National Technical Advisory Committee on Water Quality Criteria, pp.7-14;
Federal Water Pollution Control Administration, U.S. Deaprtment of the Interior, Washington, D.C.

5 *HART, B.T., 1974;*
A Compilation of Australian Water Quality Criteria, pp.162-5;
Australian Water Resources Council Technical Paper No.7;
Australian Government Publishing Service, Canberra.

6 *GELDREICH, E.E., 1972;*
Lake Buffalo recreational water quality: a study in bacteriological data interpretation;
Water Research 6, pp.913-924

7 *A.P.H.A., 1975;*
Standard Methods for the Examination of Water and Wastewater, 14th Edition, pp.954-5;
American Public Health Association, New York.

8 *REPORT, 1969;*
The Bacteriological Examination of Water Supplies, 4th Edition, pp.2-3;
Reports on Public Health and Medical Subjects, No.71, Department of Health and Social Securities, Her Majesty's Stationery Office, London.

9 *WOLF, H.W., 1972;*
The coliform count as a measure of water quality, in: MITCHELL, R. (ed.);
Water Pollution Microbiology, pp.333-45;
Wiley Interscience, New York.

10 *BUCHANAN, R. and GIBBONS, N., (eds.), 1974;*
Bergey's Manual of Determinative Bacteriology, 8th Edition, p.295;
Williams and Wilkins, Baltimore, U.S.A.

11 *MARA, D.D., 1974;*
Bacteriology for Sanitary Engineers, p.88ff;
Churchill Livingstone, Edinburgh.

12 *HART, 1974; op.cit., p.42.*

13 *REPORT, 1969; op. cit., p.3.*

14 *Ibid.*

15 *A.P.H.A., 1975; op.cit., p.913.*

16 *Ibid.*

17 *JAWETZ, E., MELNICK, J.L., and ADELBERG, E.A., 1974;*
Review of Medical Microbiology, 11th Edition, p.209;
Lange Medical Publications, Los Altos, California.

18 *MARA, 1974; op.cit., p.81.*

19 *REPORT, 1969; op.cit., p.3.*

20 *Ibid., p.5.*

21 *Ibid., p.6.*

22 *Reported in Wolf, 1972; op.cit. p.338. In his discussion Wolf wrongly gives the temperature Eijkman used as 47°C. It should be 46°C.*

23 *GELDREICH, 1966; op.cit. (reference 3), p.108.*

24 *A.P.H.A., 1975; op.cit. p.913ff.*

25 *GELDREICH, E., 1966; op.cit. (reference 3) p.16.*

26 *GELDREICH, E.E., and CLARK, N., 1966;*
Bacterial pollution indicators in the intestinal tract of freshwater fish;
Applied Microbiology, 14, p.429.

27 *GELDREICH, E., 1966; op.cit., p.65.*

28 *GELDREICH, E.E., KENNER, B.A. and KABLER, P.W., 1964;*
The occurrence of coliforms, faecal coliforms and faecal streptococci on vegetation and insects.
Applied Microbiology, 12, pp.63-69.

29 *GELDREICH, E., 1966; op.cit. p.95.*

30 *Ibid.*

31 *A.P.H.A., 1975; op.cit., p.943.*

32 *COLER, R.A. and LITSKY, W., 1976;*
Pollutants and aquatic ecosystems; in
MILLER, B.M., and LITSKY, W., (eds.);
Industrial Microbiology, p.374;
McGraw-Hill, New York.

33 *A.P.H.A., 1975; op.cit., p.942.*

34 *COLER and LITSKY, 1976; op.cit., p.374.*

35 *A.P.H.A., 1975; op.cit.*

36 *REPORT, 1969; op.cit., p.3.*

37 *HART, 1974; op.cit., pp.46-7.*

38 *COHEN, J. and SHUVAL, H.I., 1973;*
Coliforms, faecal coliforms and faecal streptococci as indicators of water pollution;
Water, Air and Soil Pollution, 2, pp.85-95.

39 *HART, 1974; supra.*

40 *GELDREICH, E.E. and KENNER, B.A., 1969;*
Concepts of faecal streptococci in stream pollution;
Journal of the Water Pollution Control Federation, 41, R336-52.

41 *GELDREICH, 1966; op.cit., p.102. Note that for pigs the fc:fs ratio is wrongly given as 0.4.*

42 *Ibid.*

43 *GELDREICH and KENNER, 1969; op.cit.*

44 *McFETTERS, G.A., BISSONNETTE, G.K., JEZESKI, J.J., THOMPSON, C.A., and STUART, D.G., 1974;*
Comparative survival of Indicator bacteria and enteric pathogens in well water;
Applied Microbiology, 27: 823-9

45 *FEACHEM, R., 1975;*
Note: an improved role for faecal coliform to faecal streptococci ratios in the differentiation between human and non-human pollution sources;
Water Research, 9: 689-690

46 *Ibid.*

47 *MARA, 1974; op.cit. p.102.*

48 *JAWETZ, MELNICK and ADELBERG, 1974; op.cit., p.80.*

49 *MARA, 1974, op.cit. p.102.*

50 *CRUICKSHANK, 1968; op.cit., p.38*

51 *Supra, p.158.*

52 *DAVIS, B.D., DULBECCO, R., EISEN, H.N., GINSBERG, H.S., and WOOD, W.B.Jr., 1968; Principles of Microbiology and Immunology, p.135; Harper and Row, New York.*

53 *JAWETZ, MELNICK, and ADELBERG, 1974; op.cit., p.61.*

54 *CRUICKSHANK, 1968, op.cit., p.158.*

55 *CARLUCCI, A.F., and PRAMER, D., 1959; Factors affecting survival of bacteria in sea water; Applied Microbiology, 7: 388-392*

56 *Ibid.*

57 *MITCHELL, R., 1972; Ecological control of microbial imbalances, in: MITCHEL, R., (ed.); Water Pollution Microbiology, p.273; Wiley Interscience, New York.*

58 *Ibid.*

59 *FAIR, G., GEYER, J., OKUN, D., 1968; Ecology and Management of Receiving Waters, in: Water and Wastewater Engineering, pp.33-5; John Wiley & Sons, New York.*

60 *Ibid., pp.33-8.*

61 *Ibid., pp.33-8.*

CHAPTER 6

SAMPLING FOR FAECAL COLIFORMS

Chapter Five traced the development of the faecal coliform test and its significance. Historically, the specific test for faecal coliforms has developed as an elevated temperature test for gas formation as described in that previous Chapter. Additionally, researchers have suggested that if faecal streptococci are enumerated in addition to faecal coliforms, and the faecal coliform to faecal streptococci ratio calculated, then human faecal wastes can be differentiated from animal faecal wastes. Tests for the determination of faecal coliforms and streptococci have been put on a standard basis by the American Standard Methods for the Examination of Water and Wastewater and various subsequent editions of this technical manual have incorporated refinements developed in research. We felt that it would be wise to standardise our laboratory work under the same conditions so that the latest edition (the 14th) of Standard Methods[1] has been used throughout our Study as the technical reference. All laboratory techniques, enumeration tables and sampling techniques used in this Study have been taken from this 14th Edition of Standard Methods. Standard Methods gives two techniques for the identification and enumeration of faecal coliforms and faecal streptococci - Membrane Filtration (MF) and Most Probable Number (MPN). To choose the most suitable technique for our purposes it was necessary to consider both.

METHODOLOGY

Membrane Filtration.

In Membrane Filtration (MF) a measured quantity of water is passed through a filter which ~~passes the water but traps~~ can retain bacteria. The filter is then incubated on a selective nutrient gel, which assists the multiplication of the sought

after bacterium and supresses the growth of other bacteria. The number of colonies of the sought after bacterium on the filter paper is the number of viable bacteria in the measured quantity of water.

~~Most Probable Number~~ Multiple Tube Dilution

In the Multiple Tube Dilution technique (MTD)

In ~~Most Probable Number~~ (~~MPN~~), a measured sample of water is diluted into test tubes containing a nutrient broth, until it is considered likely that in at least some tubes there will be no bacteria - it is a dilution to extinction technique. Replicate tubes are made to increase the accuracy. The test tubes are then incubated. The presence of bacteria is detected by biochemical reactions. The number of tubes of each dilution in which the appropriate reaction has occurred is counted and tables of most probable number are consulted to find out what is the most likely number of bacteria in 100 ml. of the original sample. For both faecal coliforms and faecal streptococci the ~~MPN~~ MTD test requires two stages: the first stage, as described above, is a presumptive test only, to be sure the organisms sought are present. The positive presumptive tubes are inoculated into tubes of the appropriate ~~selective~~ confirmation media and incubated again. The number of positive tubes are then counted and the tables consulted again to give the most probable number.

MF or ~~MPN~~ MTD?

Membrane Filtration is supplanting the older ~~Most~~ Multiple Tube ~~Probable Number~~ Dilution Method as the technique of choice in the routine testing of waters.[2] This is because of its advantages: "simplicity, speed, accuracy, reproducibility, and reduction of labour, space and material."[3] Nevertheless, for our work the ~~MPN~~ MTD technique was chosen, because unlike MF, it can be used in turbid waters.[4] As the Jordan River is at times turbid, ~~MPN~~ MTD was the technique of choice.

Sampling for Faecal Coliforms and Faecal Streptococci.

The examination technique determined the size of the sample (400 ml.). The shallowness of much of the Jordan determined the sampling technique: surface grab.

Salmonella

There are no 'standard methods' for the detection of Salmonella in Standard Methods, 14th Edition, but there are recommended methods.[5] We chose the Moore's Swab method of sampling because of the large volume usually needed to be searched to detect Salmonella. The enrichment and detection procedures are listed under media.

The Microbiology of Water Examination: Media.

Culture media are used in the identification of microbes for three purposes: growth, selection and identification of the desired organisms.[6] Media usually contain enriched nutrients (for bacterial growth), inhibitory substances (to ~~select out~~ eliminate the unwanted organisms), and an indicator (to show the presence of the sought organism).

The selection and identification of bacteria are possible only because (and to the extent that) the various species of bacteria have differing biochemical thumb-prints; biochemical activities which enable them to be separated from other microbes. Coliforms, for example, are defined as 'gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation at 35°C'.[7] By defining coliforms in this way, it becomes possible to identify coliforms by rejecting microbes which are not gram-negative, or are spore-forming, or are cocci or vibrios, or which do not ferment lactose with gas formation at 35°C, or any combination of these. Only those organisms which ~~meet~~ satisfy the definition are coliforms.

Because of the biochemical tests, it is sometimes possible to identify bacteria without examining them under the microscope. ~~which results in a great saving of time and labour, and reduces the likelihood of error due to viral similarities~~.

The media used in this project were those recommended in Standard Methods 14 ~~(1975)~~[8] for the Most Probable Number (MPN) enumeration of faecal coliforms, faecal streptococci, and Salmonellae. Each organism's identification required the use of at least two media. Those used were:-
For the identification of -

(1) Faecal Coliforms
Stage I Lauryl Sulphate (Lauryl Tryptose) Broth.
Stage II E.C. Medium.

(2) Faecal Streptococci
Stage I Azide Dextrose Broth.
Stage II Ethyl Violet Azide Broth Medium.

(3) Salmonellae
Tetrathionate Enrichment Broth.
Bismuth Sulphite Agar.
API 20 Enterobacteriaceae Strips.

To ensure standardisation of the media commercially prepared dehydrated media were used.[9] The cost of the prepared broth was greater, but it was more convenient, and as some of the constituents were not obtainable in relevant quantities, the savings in time and labour made the extra cost seem small by comparison.

Lauryl tryptose broth was preferred over lactose broth in Stage I of the faecal coliform identification as it gives fewer false positive results, and has the same sterilization procedures as the other media for faecal coliforms and faecal streptococci, whereas lactose broth does not (~~SM-14~~).[10]

SAMPLING SITES

Constraints of time, of sampling, and of laboratory space, time and techniques, limited the number of samples to ten on any single run.

Preliminary studies in February and March identified areas of interest on the River Derwent and Jordan River that we felt should be studied. These sites were mainly places where the river was being used as a recreational amenity, usually by children. Other sites were chosen because it was felt that they would indicate the quality of the water flowing into the rivers.

The sites were chosen too for their accessibility. A survey of the literature suggested that no sample should be taken more than six hours before examination in the laboratory, so it was necessary to sample at sites close to roads.

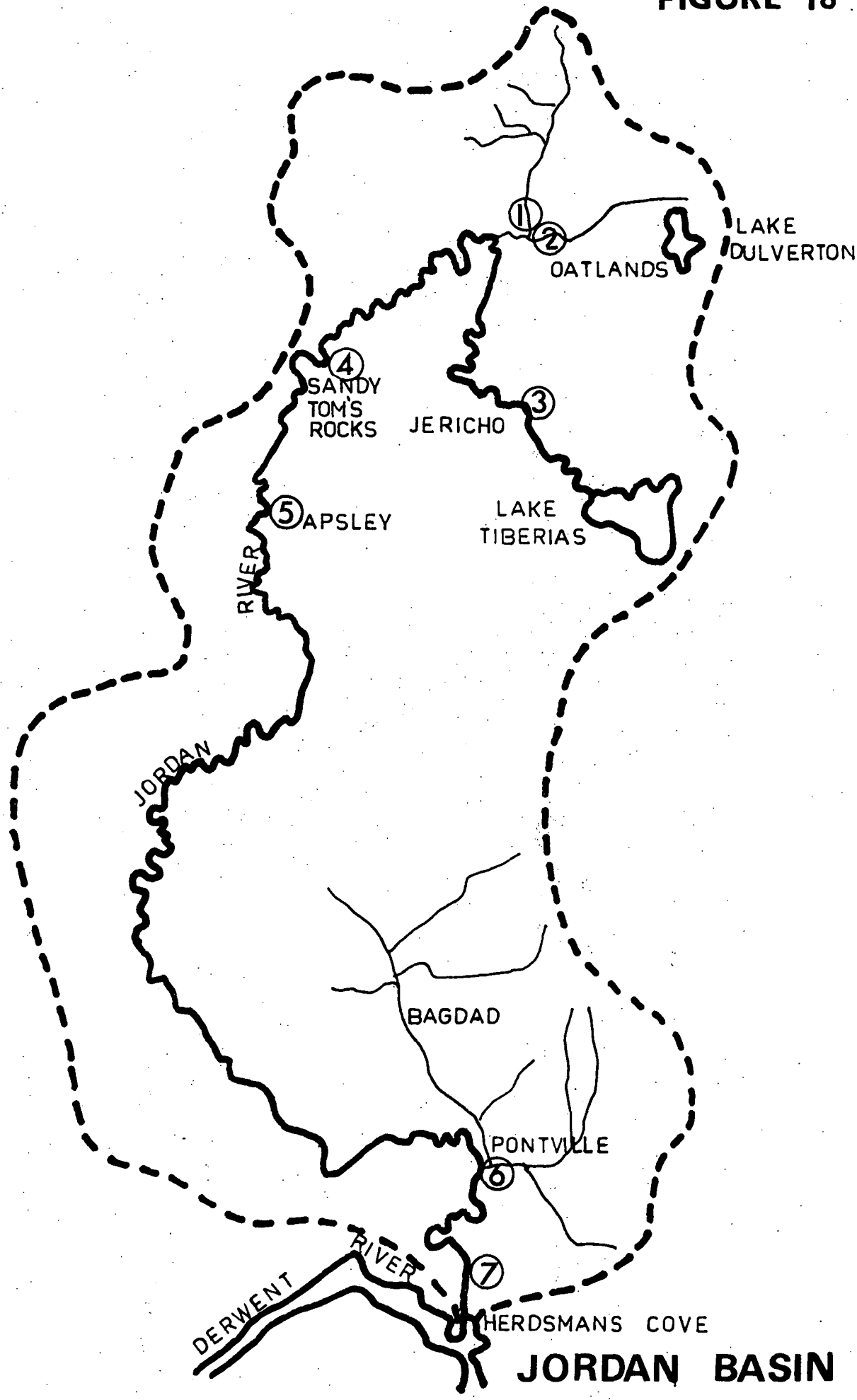
Figure 16 shows the position of the sampling sites finally chosen for the Jordan and Figure 17 the sites for the Derwent.

Jordan River Sites.

Site 1: Petherton Creek at Waverley - chosen as respresentative of the tributaries arising from the Central Plateau and having but little human or animal contamination. The sampling point was just upstream of a small road bridge (access point) and in running water. The surrounding area was cleared pasture, with some remaining trees on the hilltops. Soil was grey-brown podżolic.

Site 2: The Dulverton Rivulet -(on which this sampling site is) includes Lake Dulverton, the Oatlands township, and the Oatlands sewage treatment plant outfall in its catchment. The sampling point was shifted from upstream of a small road bridge to downstream (for easier access) after sampling revealed no marked difference in the bacterial counts. The

FIGURE 16



JORDAN BASIN SAMPLING SITES

surrounding area was a mixture of cleared land and forest; soil type is yellow podzolic.

Site 3: Upstream form the Jericho Bridge, on the Jordan River proper - chosen to sample any input from Lake Tiberias, the nominal source of the Jordan River. The catchment is mainly cleared pasture on brown earth soils.

Site 4: Sandy Toms Rocks - representative of river flow after the inflows from Oatlands and the Central Plateau. The river here runs in a narrow almost uninhabited valley. The sampling point was in running water downstream of a road bridge; upstream lay a long stagnant pool. The surrounding area is wooded savannah, on a mixture of grey-brown podzolic and meadow podzolic soils.

Site 5: Apsley - upstream of earthworks for the construction of a new bridge. Chosen as a check on Site 4. There should be few observed differences on these sites. Similar in vegetation and soil type to Site 4. This site was later abandoned when flooding caused by the bridge construction rendered the sampling site inaccessible.

Site 6: Pontville Ford - chosen because it is the junction of the Jordan River and the Bagdad Rivulet. It is also a popular recreation site with children, both in summer, when they splash around in the water, and in the cooler months. This area is closely settled and enables a comparison to be made with the more sparsely populated regions at Sites 4 and 5. Surrounding area mainly cleared, with dark brown earth, black prairie soils.

Site 7:Conservation Area, Herdsmans Cove - a recreational area, both fishing and swimming being observed, as well as numerous campfire sites. Appears to be used to as an unofficial rubbish dump. Estuarine. Cleared land surrounds the Conservation Area. Soils are brown on basalt.

River Derwent Sites (Figure 17).

The sites are numbered from 8 to 11 (as sampling proceeded downstream) following on the Jordan sites 1-7). There is no significance in this; all sites are above the confluence of the Derwent and the Jordan. Sites 8-10 are on the North bank of the Derwent, Site 11 is on the South bank.

Site 8: Lawitta, on a semi-submerged tree near the take off point for the pumping station for the West Derwent water supply scheme - this sampling station is in a zone where no effluents are permitted to enter the Derwent. This site was used as an upstream control to check that there were low bacterial counts above New Norfolk.

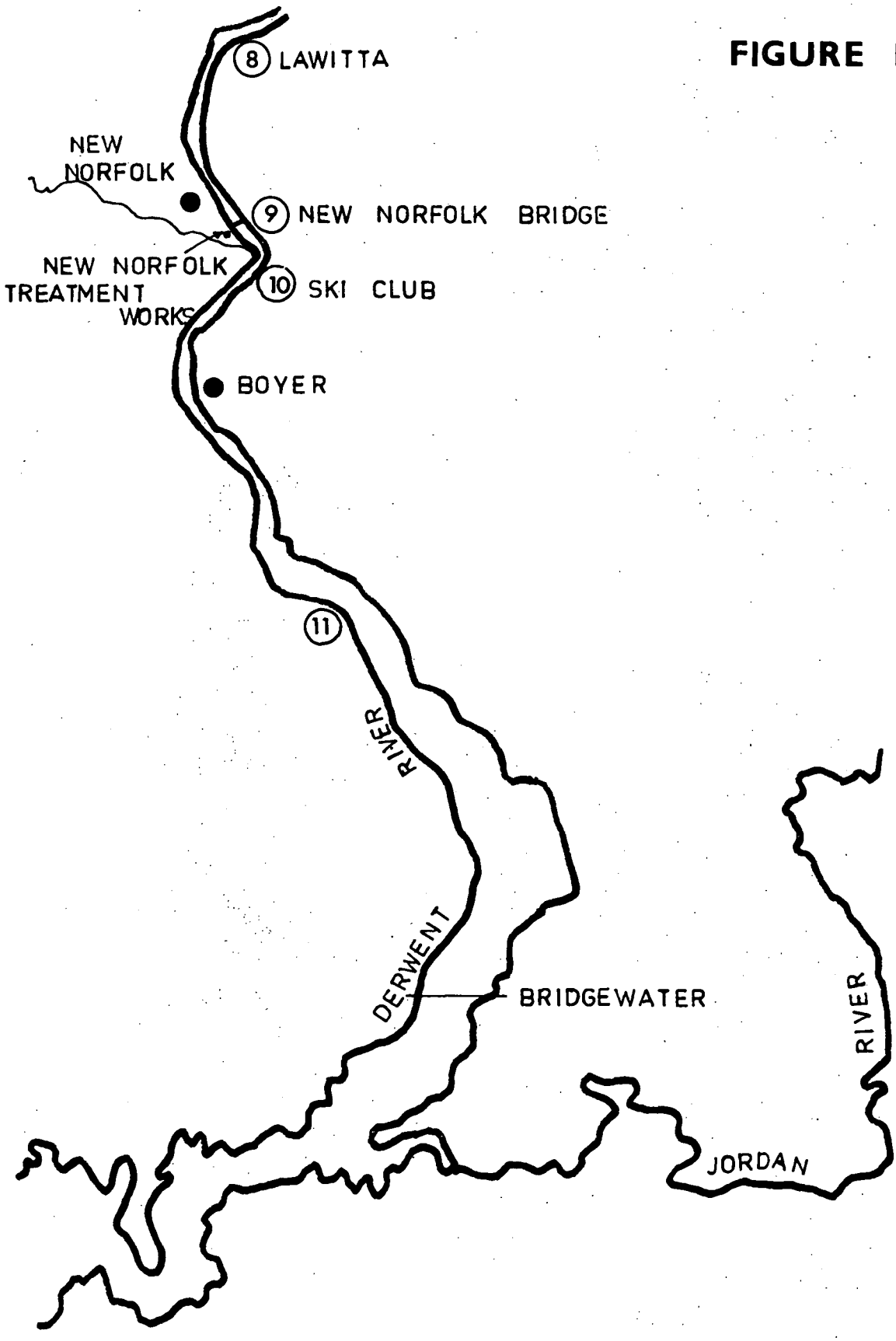
Site 9: The launching ramp for the rowing club in New Norfolk - chosen for its accessibility and because of its popularity with children.

Site 10: The launching ramp at the Nomads Water Ski Club - this site is about 100 metres downstream and across the Derwent from the New Norfolk sewage treatment plant. Water skiing is a sport in which, if one falls off the skis, it is difficult not to ingest some water, and so it is a good example of a primary body contact sport.

Site 11: On the South bank below Boyer and just above ~~an~~ a water ski ~~aquatic~~ centre - this site was chosen to see if the faecal coliforms rose below Site 10 and the newsprint mill.

[1] *APHA, 1975;*
Standard Methods for the Examination of Water and Wastewater, 14th Edition;
American Public Health Association, New York.

FIGURE 17



DERWENT SAMPLING SITES

2 *MOWAT, A., 1976;*
Most probable number versus membrane filter on chlorinated effluents;
Journal of the Water Pollution Control Federation, 48: 724-8.

3 *Ibid.*

4 *APHA, 1975; op.cit. p.928.*

5 *Ibid., pp.955-60.*

6 *SCARPINO, P.V., 1971;*
Bacterial and viral analysis of water and wastewater;
in: CIACCIO, L.L., (ed.);
Water and Water Pollutiom Handbook, Volume 2, p.652-3;
Marcel, Dekker, Inc., New York.

7 *APHA, 1975; op.cit., p.913.*

8 *Ibid., pp.886-903.*

9 *Ibid., p.892.*

10 *Ibid., p.916.*

CHAPTER 7

SAMPLING RESULTS

Sampling was carried out at fortnightly intervals from Friday 8th April to Friday 2nd September, 1977. The fortnightly interval was chosen because of the labour involved in making up media, preparing sample test tubes and of processing the tubes. After the initial run we found it necessary to prepare test tubes for 10 ml., 1 ml., o.1 ml. and 0.01 ml. dilutions. With ten samples to process and five tubes for each dilution it then required four hundred tubes for each stage of the two stage test for confirmed faecal coliforms and streptococci. This meant the preparation and processing of eight hundred test tubes for each sample run. Friday was chosen for sampling as the laboratory was free only at weekends. With the low coliform and streptococci counts observed some reduction of test tube numbers was later possible, since negative tubes could be discarded in the presumptive stage 1 test. The need for assistance in handling these large numbers of tubes highlights the unpopularity of the ~~MPN~~ MTD test procedure and the resultant search by testing authorities for alternative, equally reliable and less time consuming testing. The MF procedure is preferable for this reason alone, yet we suspect that its drawback of not working with turbid waters means that testing authorities ~~will tend to avoid sampling such waters~~ are restricted to use of the MTD technique when examining these waters.

Our results are presented as confirmed counts of faecal coliforms and faecal streptococci in this Chapter.

The results are analysed preparatory for discussion in Section D. Partway through the sampling we added a site on the Derwent at Bridgewater as our early results did not give coliform levels compatible with those of the Department of the Environment and it was evident that we had not identified the coliform source. At the same time, because of limitations of equipment, we then had to abandon a site. Site 5 on the Jordan was abandoned as being of least interest.

The results from the new Site 11 were quite startling in that they were markedly higher than those at Site 10, indicating a coliform source between these two sites. As it was impossible to sample between these sites from the river bank, a boat was used and two sampling runs made between Sites 10 and 11. The results of these boat sampling runs are given in this Chapter. They indicate Boyer to be the source of the coliforms ar Bridgewater. They are discussed in particular detail in Section D.

RESULTS

The bacteriological results for the combined Jordan-Derwent sampling runs are summarised in Table 12. Faecal coliforms (fc)/100 ml., faecal streptococci (fs)/100 ml., and the fc:fs ratio for the eleven sampling runs at each site are shown. We did not sample Sites 5 and 11 eleven times; Site 5 was abandoned to accommodate Site 11 as a new site of importance partway through the sampling programme. Table 12 also shows the geometric mean (G) of faecal coliforms/100 ml. for each site.

TABLE 12

Results of Sampling Runs down the Jordan and Derwent Rivers.
Faecal Coliforms (including G†), Faecal Streptococci and fc:fs ratio.

	TEST RUN DATE		1 8.4.77	2 22.4.77	3 6.5.77	4 20.5.77	5 3.6.77	6 17.6.77	7 1.7.77	8 15.7.77	9 29.7.77	10 12.8.77	11 2.9.77	G†
JORDAN RIVER	SITE 1	fc	1300	790	110	130	130	130	130	700	490	79	230	246
		fs	79	33	110	75	130	130	130	490	700	63	790	
		fc:fs	16.5:1	23.9:1	1:1	1.7:1	1:1	1:1	1:1	1.4:1	0.7:1	1.3:1	0.3:1	
	SITE 2	fc	330	490	79	330	79	130	130	490	170	130	230	193
		fs	170	79	49	330	49	79	110	490	700	170	330	
		fc:fs	1.9:1	6.2:1	1.6:1	1:1	1.6:1	1.6:1	1.2:1	1:1	0.2:1	0.8:1	0.7:1	
	SITE 3	fc	79	17	49	49	49	79	49	490	70	70	460	78
		fs	23	27	33	140	23	49	79	220	230	23	170	
		fc:fs	3.4:1	0.6:1	1.5:1	0.4:1	2.1:1	1.6:1	0.6:1	2.2:1	0.3:1	3.0:1	2.7:1	
	SITE 4	fc	70	17	33	70	94	23	49	230	70	33	79	54
		fs	23	13	49	23	33	23	70	70	130	31	33	
		fc:fs	3.0:1	1.3:1	0.7:1	3.0:1	2.8:1	1:1	0.7:1	3.3:1	0.5:1	1.1:1	2.4:1	
	SITE 5	fc	230	70	79	230	23	49	170	79				90
		fs	49	49	110	330	170	170	130	230				
		fc:fs	4.7:1	1.4:1	0.7:1	0.7:1	0.1:1	0.3:1	1.3:1	0.3:1				
	SITE 6	fc	490	230	280	230	170	230	330	330	490	110	220	260
		fs	330	46	330	230	33	94	790	490	2400	23	23	
		fc:fs	1.5:1	5.0:1	0.8:1	1:1	5.2:1	2.4:1	0.4:1	0.7:1	0.2:1	0.5:1	9.6:1	
	SITE 7	fc	230	230	330	330	220	280	230	230	790	130	330	273
		fs	70	49	1300	330	130	130	230	330	2400	46	23	
		fc:fs	3.3:1	4.7:1	0.3:1	1:1	1.7:1	2.2:1	1:1	0.7:1	0.3:1	2.8:1	14.3:1	
DERWENT RIVER	SITE 8	fc	79	22	33	49	49	49	49	49	140	49	49	51
		fs	46	17	49	130	33	33	49	110	110	23	23	
		fc:fs	1.7:1	1.3:1	0.7:1	0.4:1	1.5:1	1.5:1	1:1	0.4:1	1.3:1	2.1:1	2.1:1	
	SITE 9	fc	1700	230	170	79	33	79	110	79	79	79	220	129
		fs	330	23	23	70	79	49	460	330	79	79	170	
		fc:fs	5.2:1	10.0:1	7.4:1	1.1:1	0.4:1	1.6:1	0.2:1	0.2:1	1:1	1:1	1.3:1	
	SITE 10	fc	2400	350	16000	23	23	79	33	33	79	130	230	157
		fs	220	33	790	170	49	33	49	130	79	110	110	
		fc:fs	10.9:1	10.6:1	20.3:1	0.1:1	0.5:1	2.4:1	0.7:1	0.3:1	1:1	1.2:1	1.8:1	
	SITE 11	fc					130	490	790	790	940	1300	3500	776
		fs					170	170	33	280	460	94	130	
		fc:fs					0.8:1	2.9:1	23.9:1	2.8:1	2.0:1	13.8:1	26.9:1	

†G = GEOMETRIC MEAN

The faecal coliforms/100 ml. for each site over the sampling period have been charted for the Jordan in Figure 18 and for the Derwent in Figure 19. These figures allow ready comparison of sites on each river.

Figure 20 plots the geometric means of faecal coliforms/ 100 ml. of all sites and enables a ready comparison between the two rivers.

The water quality criteria for recreation of 200 faecal coliforms/100 ml. discussed in Chapter 4 are marked on the graphs in all Figures.

Temperature, conductivity and dissolved oxygen levels for the sample runs were measured (when equipment was available) and are given in Appendix 2. As no variations or anomalies were observed in these readings or in pH readings of the samples in the laboratory which were of environmental significance, they will not be discussed in detail.

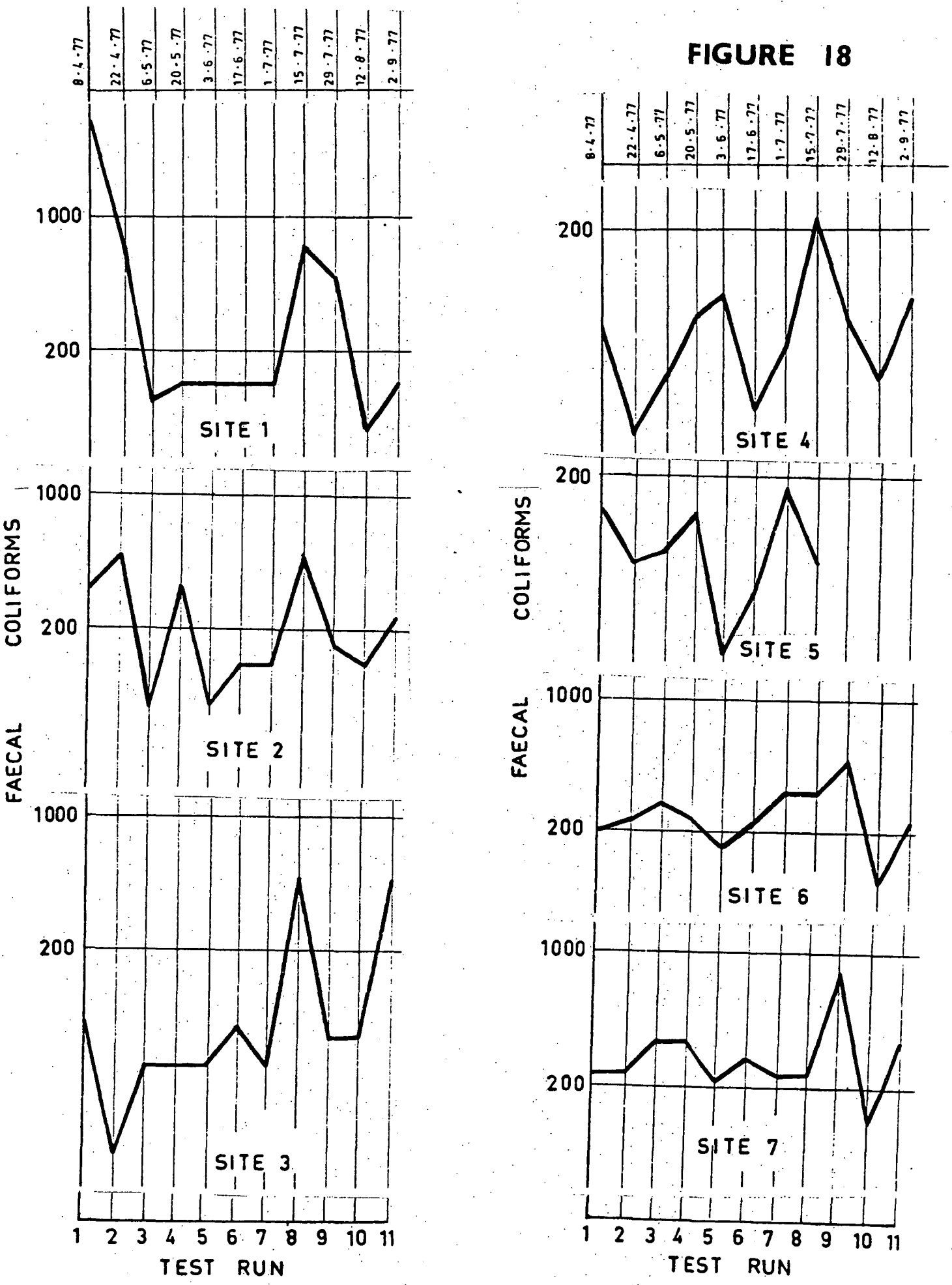
Jordan River - Faecal Coliforms.

Faecal coliforms were high, compared to later observations, for the initial run at each site. (Figure 18). The first four sites gave another peak on the 15th July on the eighth sampling run. Sites 1, 6 and 7 have the highest geometric means (Figure 20).

Jordan River - Fc:Fs Ratio.

The fc:fs ratios at each site varied considerably. (Table 12). At most sites they were high at first and then declined. There appears to be no internal consistency with the fc:fs ratio fluctuating markedly at the same site from sampling run to sampling run.

FIGURE 18



JORDAN RIVER

FAECAL COLIFORM PLOTS

Derwent River - Faecal Coliforms.

Initially the faecal coliform counts were high at Sites 9 and 10, but had dropped markedly by the second run.(Table 12, Figure 19). A peak at Site 10 on 6th May (Run 3) coincided with observed low river flow. Site 8 remained low throughout the Study whilst Site 11, added partway through the Study, increased markedly over time from a low initial faecal coliform count.

River Derwent - Fc:Fs Ratio.

The fc:fs ratios at sites 9 and 10, initially high, dropped; that of Site 11 went from low to high. At Site 8, although the fc:fs ratios varied from run to run, they did not fluctuate as markedly as those of the other Sites.

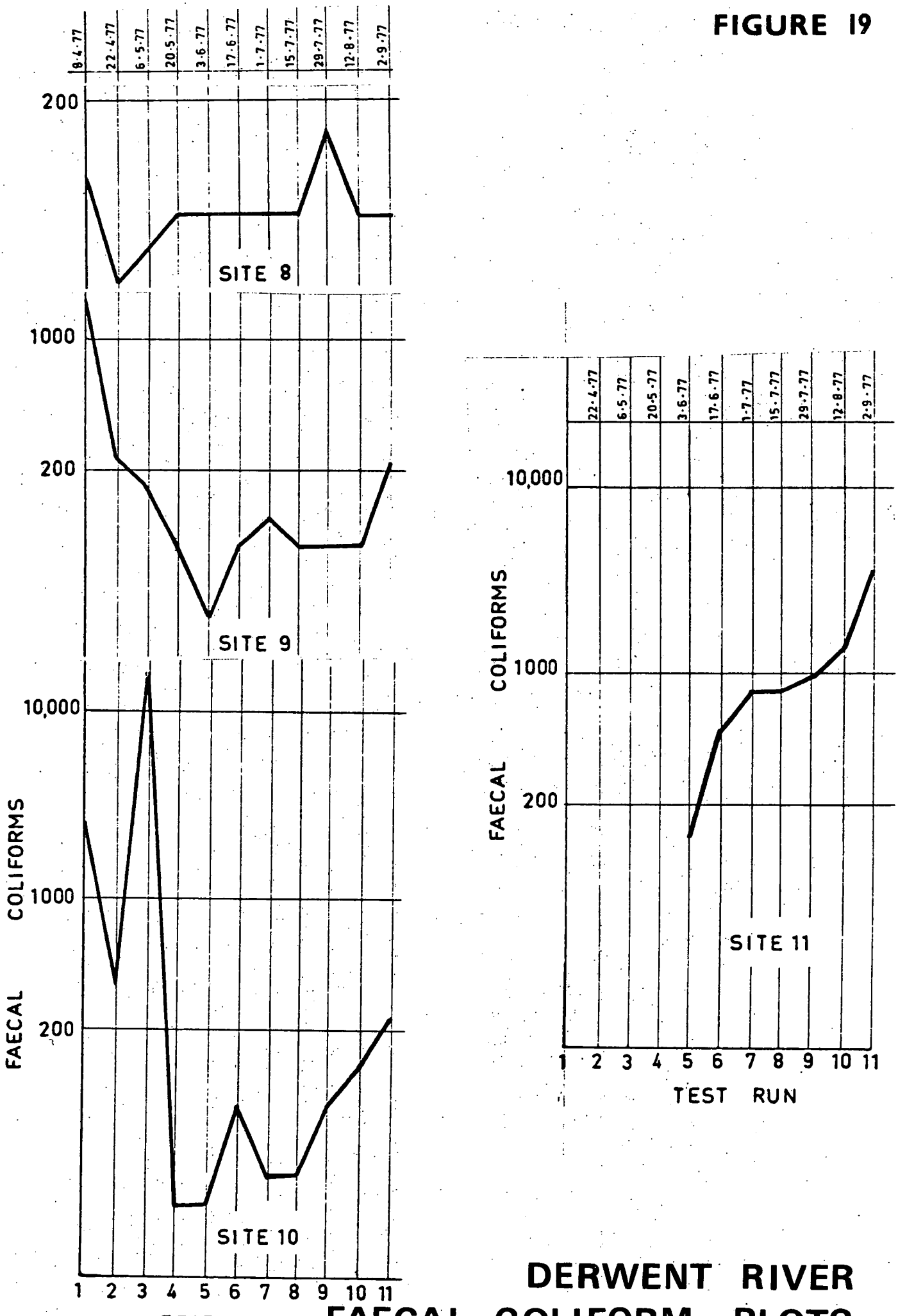
Boat Sampling Runs.

The early runs (Numbers 1 to 4) did not indicate levels of coliforms sufficiently high to explain the readings reported by the Department of the Environment at Bridgewater (Figure 2). It was obviously necessary for us to sample the Derwent near Bridgewater and we chose Site 11. This Site (Figure 19) indicated that a coliform source existed between Sites 10 and 11.

Since it was not possible to get to the river banks between these two Sites, as the banks were composed of extensive swamps or private property, we decided to use a boat. Two sample runs were made, the first in July and the second in September, so that we could obtain the biggest possible time spread in the time available. The results of these boat runs are recorded in Table 13 with Figure 21 giving a plot of the faecal coliforms for each trip.

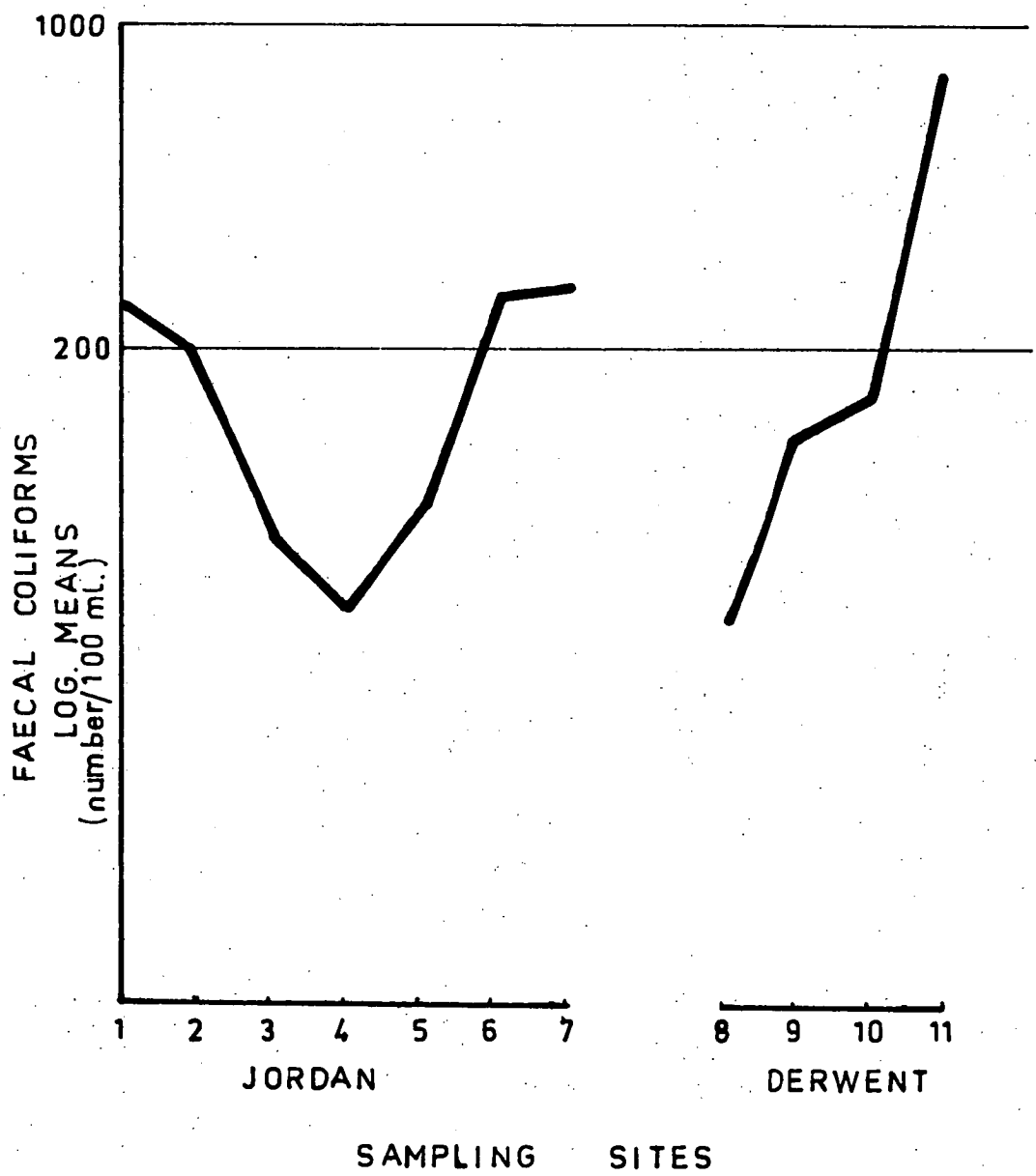
The results for each trip were recorded separately as the two trips are not truly comparable, which prevented means

FIGURE 19



DERWENT RIVER FAECAL COLIFORM PLOTS

FIGURE 20



JORDAN - DERWENT
FAECAL COLIFORMS
GEOMETRIC MEANS

being calculated. The ≥24,000 faecal coliforms recorded for the mill effluent on the first trip (22.7.'77) was the maximum number of faecal coliforms able to be counted. An additional one in ten dilution of the sample of the second trip enabled the Most Probable Number of faecal coliforms to be enumerated more exactly.

TABLE 13

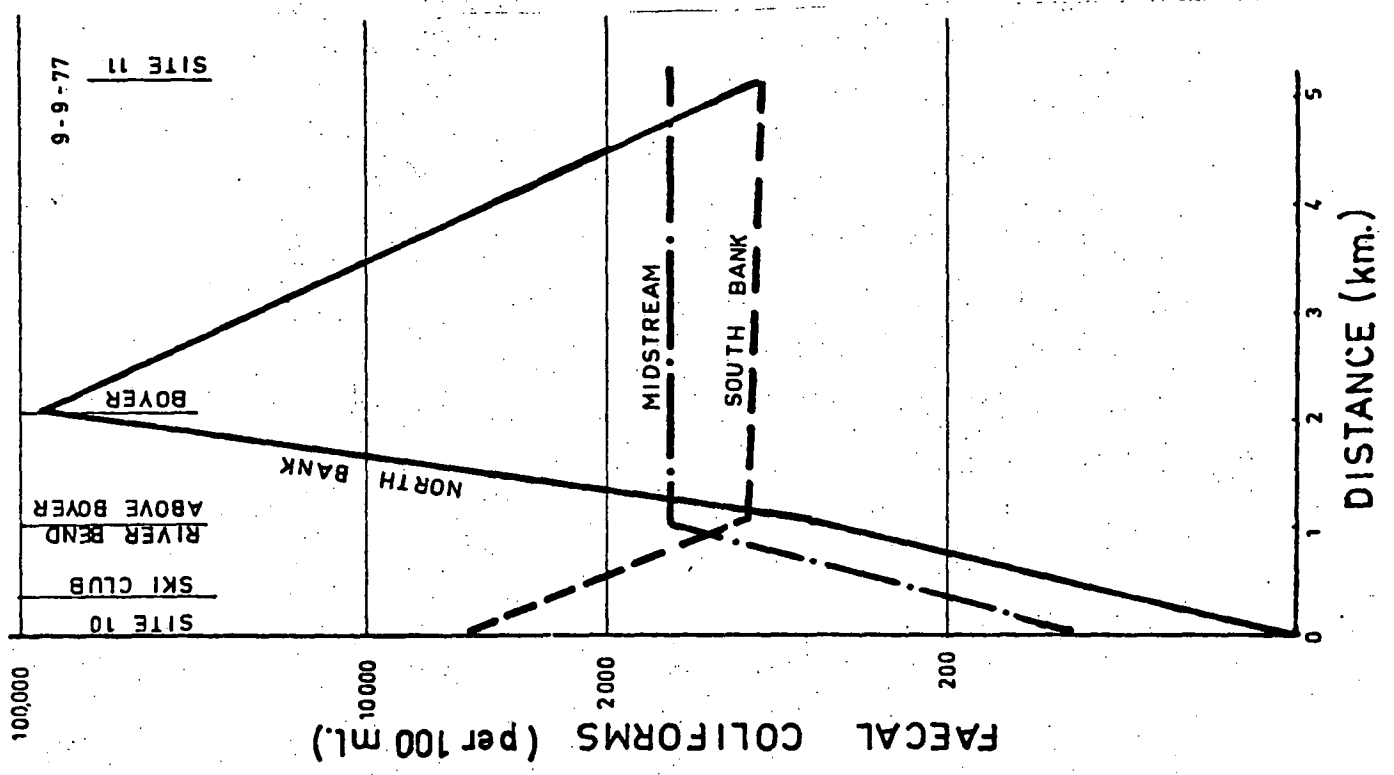
River Derwent: Faecal Coliforms, Faecal Streptococci and Fc:Fs Ratios for Two Sampling Runs by Boat.

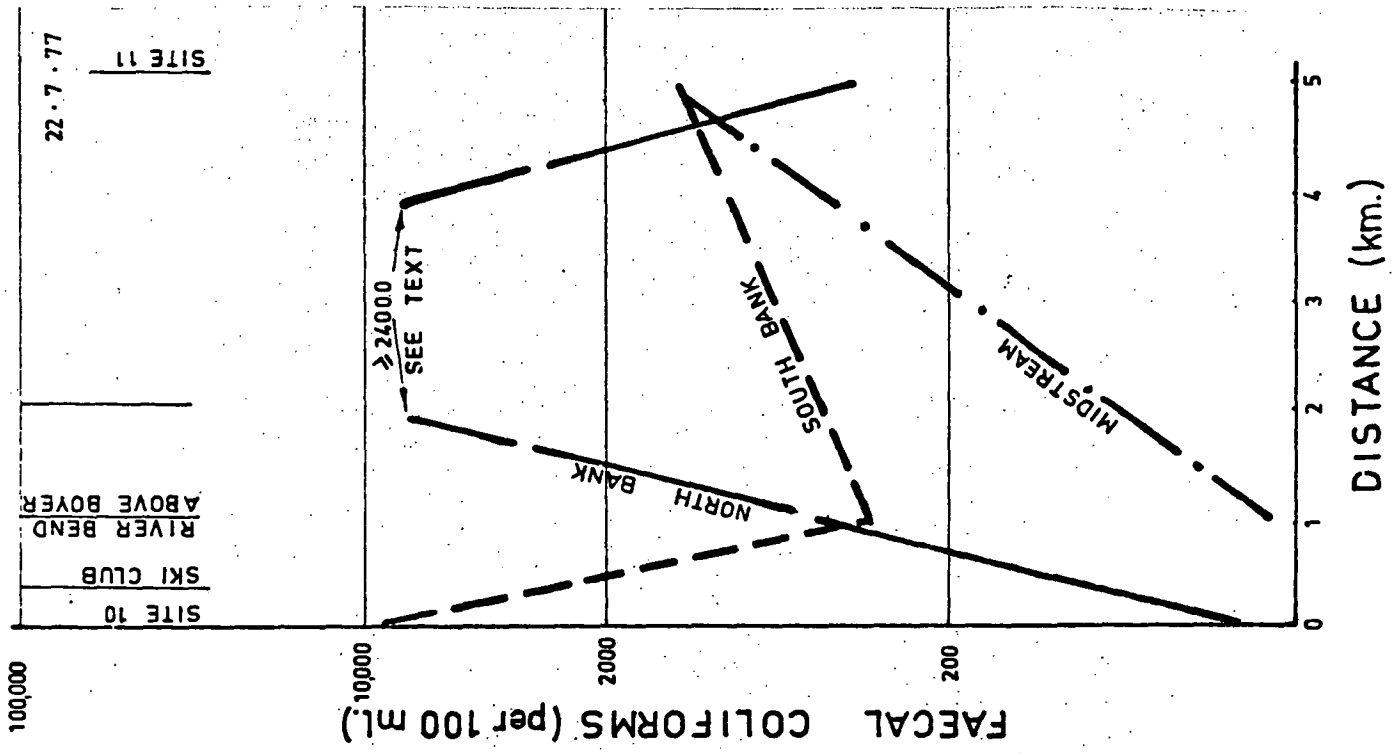
Sampling Site Position		22.7.'77 fc	fs	fc:fs	9.9.'77 fc	fs	fc:fs
Site 10	North Bank	23	46	0.5	23	2	11.5
below N.Norfolk sewage outfall.	Midstream	not collected - bottle contaminated			79	14	5.6
	South Bank	9200	1100	8.4	5400	9200	0.6
Bend above pulp and paper mill.	North Bank	490	31	15.8	23	<0.5	>40
	Midstream	23	33	0.7	1300	280	4.6
	South Bank	350	230	1.5	790	130	6.1
Pulp mill effluent.		≥24000	172	139.5	92000	3500	26.3
Site 11	North Bank	490	46	10.7	700	490	1.4
below mill outfall.	Midstream	1400	23	60.9	1300	330	3.9
	South Bank	1300	23	56.5	700	490	1.4

The midstream sample at Site 10 (opposite the Nomads' Ski Club launching ramp and just below the outfall from the New Norfolk sewage treatment plant), was not collected because the top of the sampling bottle was accidentally dropped and unsterilized.

Marked variation in the bacterial indicator counts from bank to bank at Site 10 were observed.(Figure 21). The river

FIGURE 21





DERWENT RIVER
FAECAL COLIFORM PLOTS
BOAT SAMPLING

flows rapidly here and it seems that mixing is poor.

Salmonella.

Salmonella were sought at Sites 6 and 7 on the Jordan, and Site 10 on the Derwent. Moore's gauze swabs were left in the rivers for 5 days and the samples for each site were pooled and examined. No Salmonella were found.

SECTION D:

INTERPRETATION AND EVALUATION

CHAPTER 8

INTERPRETATION AND EVALUATION

We set out on this Study with the specific aims of determining the origin of the large numbers of faecal coliforms observed by others in the Derwent River at Bridgewater; of assessing the applicability of the Fc:Fs ratio to the Derwent/Jordan river system; of assessing health hazards in the Derwent/Jordan river system and of environmentally characterising the Jordan as a background for interpreting and evaluating the sample results.

Our sampling gave us two major findings. Firstly, a paper pulp mill appeared to be the major source of faecal coliforms, and secondly, the very large animal population of the Jordan has apparently little influence on that River with regard to faecal wastes.

In this concluding section, these findings and the sampling results are integrated with the various data inputs from the Chapters of the previous Sections. The integration is then interpreted and evaluated to form the conclusions of this Report as stated briefly in the Introduction. Because of its importance and the implications of the possibility of the coliform discharge from Boyer containing pathogenic Klebsiella, we have given it a special Chapter of its own. Chapter Nine, the Boyer Chapter, follows this Chapter.

Once again, and now particularly so, since the coliform source in each River is shown to be different, it has been found convenient to discuss the Jordan and Derwent separately. We begin with the Jordan.

THE JORDAN RIVER

Faecal Coliforms.

The faecal coliform counts are surprisingly low. The initial peak at the beginning of sampling (Run 1) and in the middle (Run 8 for Sites 1 to 4)(Figure 19), coincide with the first soaking rain of autumn and of heavy rain on 15th July[1] respectively, giving increased run off and river flow. The peak of 15th July did not show up downstream of Site 4, (Figure 19). The flow gauge in the River is situated at Mauriceton below Site 5. As the river flow time from the Dulverton Rivulet (Site 2) to Mauriceton is about 22 hours[2] it would seem that increased run off leading to increased river flow does correlate with increased faecal coliforms in the River. An increase in indicator organisms under these conditions has been reported in the literature.[3,4]

An additional influence on the early high coliform counts of April may be the release of adsorbed faecal coliforms from sediments following dilution of salt content in receiving waters by rainwater runoff.[5]

The only sites with faecal coliform counts consistently above 200/100 ml. are Sites 1, 6 and 7, Petherton Creek, Pontville Ford and Herdsman's Cove respectively. (Figures 19, 20). We predicted in Section B that the Ford was a likely place to exhibit faecal pollution due to the confluence there of the Bagdad and Strathallan Rivulets and of the development by man of the catchments of those Rivulets. Site 1 coliforms are attributed to the closeness of a farmhouse to the creek upstream of our sampling site. Site 7 at Herdsman's Cove is downstream both of the Ford and of the Brighton township sewage treatment lagoon. Sites 6 and 7 are both recreational areas as noted in Section B. The continual low counts at the other sites are thought to be due to the remoteness of these sites from man and animal activity whilst the low counts in general are attributed to the aridity of the area and the lack of sufficient rain to transport coliforms to the river.

The savannah grassland of the areas around the sites may also exert an environmental influence on deposited coliforms by trapping them whilst affording little protection from the elements. The irrigation of pastures around the Brighton region (Section B) may have an influence on the higher readings observed at Site 7 in contrast to the lack of irrigation in other regions. Investigation of this aspect at Site 7 as against the sewage lagoon effect would appear worthy of attention, particularly since Site 2 did not show any marked influence of the sewage lagoon at Oatlands.

Fc:Fs Ratio.

Whilst there are fluctuations in the fc:fs ratio we consider that, at the low coliform counts observed, they are more likely to be caused by inherent errors in the ~~Most~~ multiple Tube Dilution ~~Probable Number~~ Technique[6] rather than by occurrences at the sampling sites. The high ratios of the First Run may also in part be due to the release of adsorbed faecal coliforms from sediments as discussed above.

THE DERWENT RIVER

Faecal Coliforms.

Our approach to the Derwent was to sample sites which were used for recreation or which were thought to be sites where faecal coliforms should exist. Site 8 at Lawitta was chosen as a baseline which should be relatively uncontaminated; Site 9 at the rowing club boat ramp was chosen to detect discharge from the town of New Norfolk and Site 10 to detect the effect of the sewage treatment plant. We did not sample Bridgewater itself as, in the absence of an obvious source of adequate size, we considered the levels of bacteria there to be a symptom of contamination elsewhere.

Our initial sampling results (Runs 1 to 5) did not

indicate a coliform source of adequate size to explain the Bridgewater coliform counts observed by the Department of the Environment. We postulated either that mixing in the River was not occurring and that we were not observing the treatment plant effluent, or that the wastes of the pulp mill were acting as a nutrient.

Site 11, some distance downstream from the mill's effluent discharge point, and on the opposite bank of the River to ensure mixing had occurred, was added to see if the faecal coliforms had increased below the mill.

At about this time, an article by Dufour and Cabelli[7] was mentioned to us indirectly as evidence for the inaccuracy of the faecal coliform elevated temperature test, because Klebsiella species gave a positive faecal coliform reponse and negated its value as a test for faecal coliforms. The article made us aware of the literature reporting faecal coliform positive bacteria (mainly Klebsiella pneumoniae) occurring in large numbers in carbohydrate-rich effluents, such as those from pulp and paper mills.

The results from Site 11 confirmed that large numbers of faecal coliforms were present in the Derwent below the newsprint mill (Table 12, Figure 19), and suggest that contact with the water at Site 11 or nearby may be a health hazard. Figure 20 shows the dramatic rise in faecal coliforms between Sites 10 and 11. However, we were unable to tell whether mill effluent was the source of the faecal coliforms, or if sewage bacteria from New Norfolk were multiplying in the River, despite the low temperatures.

24 hour incubation at 37^{C}, then re-examination of samples taken at Sites 10 and 11 did not resolve the issue. (Table 14).

TABLE 14

Effect of 24 Hours of Incubation at 37^{C}
on Faecal Coliform Counts - (15.7.'77)

Site	Faecal Coliforms/100 ml. Before Incubation	After Incubation
10	33	17
11	790	16000

It can be seen that the faecal coliform count from Site 10 (above the newsprint mill) dropped after incubation. The faecal coliform count at Site 11 (below the mill) rose markedly. (Faecal streptococci were re-examined after incubation only at Site 11, where they fell from 280/100 ml. to 110 after incubation, the fc:fs ratio changing from 2.8 to 145). The results suggest that nutrients for faecal coliforms (though not for faecal streptococci apparently), were entering the River between Sites 10 and 11 - the stretch which receives the effluent from the pulp and paper mill. We were unable to tell from this experiment whether the bacteria multiplying on incubation were coming from the mill effluent, or whether they came from further upstream and were multiplying in the River. This led us to sample from a boat the River between Sites 10 and 11.

Two sampling runs were made; samples being taken at Site 10, at the bend above the mill (the effluent runs down the bank into the River some distance downstream), and at Site 11. Sampling was near both banks and in midstream. Samples of sawdust-smelling, treacle coloured effluent were also taken as it cascaded down the bank into the River. The results are given in Table 13 and Figure 21. Consideration of Figure 21 shows that the faecal coliform counts, below the sewage plant but above Boyer, are odd. The plant is situated on the South bank and, given lack of mixing, the midstream

and North bank counts remain low at the treatment plant site for both runs. However, on moving downstream to above Boyer, whilst the North bank count rises to match the South bank count, the midstream count remained low for the first run and rose for the second run. We suspect that a combination of tidal effects and the strong lamina flow of the River is the cause of this observed phenomena. Our limited resources of time and culture media did not allow us to explore this further.

Similarly we were unable to sample across the River at the point where the effluent entered, because of limitations on the number of samples that could be processed. We thought it was more important to establish the framework in which the impact of the effluent was occurring, rather than study the immediate impact of the effluent on the River at the point of discharge. Therefore only the effluent itself was sampled, and the River below the effluent discharge (by which point we hoped mixing had occurred), rather than the River adjacent to the discharge. Further, the River at the point of entry of the effluent was inaccessible to the public excepting by boat, and hence did not pose a direct health hazard.

By Site 11 the mixing of the water and effluent was moderately complete. Curiously, the water near the North bank of the River which was the bank from which the effluent entered the River, was less contaminated than were the waters of the main (midstream) current.

The effluent from the mill had very high faecal coliform counts. We were not expecting such high faecal coliform counts, and the ≥24,000 faecal coliforms/100 ml. recorded for the first run represents our inability to count higher than the dilutions of effluent sample chosen. A further one in ten dilution of the sample on the second run enabled us to count the faecal coliforms as probably 92,000/100 ml. of effluent (the 95% confidence limits for this number are 30,000

and 320,000 faecal coliforms/100 ml.).

The conclusion is that faecal coliforms are discharged into the Derwent from the pulp and paper mill, probably along with nutrients. Although we did not attempt to incubate and re-examine the effluent as we barely had enough culture media for that last sampling run without reincubation, there are no factories or food processing plants (or even major streams or rivers between Sites 10 and 11), other than the pulp and paper mill.

The mill discharges 100 megalitres of effluent per day[8] containing probably 92,000 faecal coliforms in each 100 millilitre, i.e. a total daily coliform discharge of 90×10^{12} faecal coliforms.

The sewage treatment plant at New Norfolk discharges 790 Kilolitres of effluent per day from a primary treatment process.[9] The measurements by us of coliforms on the two boat trips at this site were taken as close to the plant outfall as we could get and gave a probable count of 9,200 faecal coliforms per 100 ml. McCoy[10] gives a median range of between 5.5×10^6 and 0.2×10^6 faecal coliforms as being an observed count of a sewage treatment plant effluent dependent upon the season. The winter median was 5.5×10^6. Whilst our results on the treatment plant do not indicate such high coliform counts we calculate, using McCoy's high winter levels, that the plant may give a peak discharge of 43.45×10^{12} faecal coliforms per day. This is slightly less than half the daily faecal coliform discharge of the pulp mill.

A small sewage treatment plant was constructed in the Bridgewater area on the Derwent North bank, West of Herdsman's Cove in 1971, and in that year the population of the area was 1,360 persons.[11] This plant was then too small to be the source of the observed Bridgewater coliforms. Even now (1977) the discharge is still only 790 Kl. per day.[12]

We conclude that the Boyer paper pulp mill is the major source of faecal coliforms in the Study Area.

Fc:Fs Ratios.

Like those for the Jordan, the fc:fs ratios in the Derwent fluctuated markedly over time, even at the same site. Samples taken near the New Norfolk sewage treatment plant should have given consistent readings of 4.0 or above, but this did not occur. The effluent from the pulp and paper mill had a very high fc:fs ratio in the first sample, and though less elevated, the second sample too was in the range classed as probably human by Geldreich and Kenner. As the sites sampled were within 24 hours flow of the source of bacteria, we feel that the odd results were due to the technique itself not being as powerful as its promoters would like to believe. We suspect that had we been using Membrane Filtration rather than ~~Most Probable Number~~ Multiple Tube Dilution, the results would have been more consistent, as less error is likely in determining colony counts than deciding whether a ~~test-tube is turbid or not~~ media. ✓ O.K.

Any further work on the Derwent should be done by Membrane Filtration where possible, though the high suspended solids level in the newsprint mill effluent will most likely necessitate the use of ~~M.P.N.~~ MTD. there.

1 *RIVERS AND WATER SUPPLY COMMISSION, 1977;*
Jordan River Flow Gauge Records 1977;
Rivers and Water Supply Hydrology Records, Hobart.(unpublished).

2 *STEANE, J.D., 1967;*
Water Resources of the River Jordan, p.20;
Tasmanian Water Resources Survey, Third Report;
Rivers and Water Supply Commission, Hobart.

3 *FEACHEM, R., 1974;*
Faecal coliforms and faecal streptococci in streams in the New Guinea Highlands;
Water Research, 8: 367-374.

4 *LIN, S., EVANS, R., and BEUSCHER, D., 1974;*
Bacteriological assessment of Spoon River water quality;
Applied Microbiology, 28: 288-297

5 *ROPER, M.M., and MARSHALL, K.C., 1974;*
Modification of the interaction between E. coli and bacteriophage in saline sediment;
Microbial Ecology, 1: 1-13

6 *APHA, 1974;*
Standard Methods for the Examination of Water and Wastewater, 14th Edition, p.923;
American Public Health Association, New York.

7 *DUFOUR, A.P., and CABELLI, V.J., 1976;*
Characteristics of Klebsiella from textile finishing plant effluents;
Journal of the Water Pollution Control Federation, 48: 872-9.

8 *DEPARTMENT OF ENVIRONMENT, HOUSING AND COMMUNITY DEVELOPMENT, 1977;*
Pollution Abatement Costs in the Pulp and Paper Industry, p.45;
Australian Government Publishing Service, Canberra.

9 *SCOTT & FURPHY ENGINEERS PTY. LTD., 1977;*
Southern Metropolitan Sewage Study, p.59;
Tasmanian Government Printer, Hobart.

10 *McCOY, J.H., 1971;*
Sewage pollution of natural waters; in
SYKES, G., and SKINNER, F.A. (eds.);
Microbial Aspects of Pollution, p.37;
The Society for Applied Bacteriology Symposium Series No.1;
Academic Press, London.

11 *SCOTT & FURPHY ENGINEERS PTY. LTD., op.cit. p.211.*

12 *SCOTT & FURPHY ENGINEERS PTY. LTD., op.cit. p.59.*

CHAPTER 9

BOYER

The Australian Department of Environment, Housing and Community Development published in 1977 a Report on pollution abatement costs in the Australian pulp and paper industry. This Report examined all known polluting wastes from the pulp industry and stated (p.26) 'microrganisms, such as coliforms, the main bacterial constituent of stormwater and septic tank runoff, are a minor consideration in the industry.'

In this Chapter we examine our sampling of the Boyer effluent against a background of recently published research work on the occurrence and significance of micro-organisms in paper pulp effluent which are shown to react positively as faecal coliforms to the elevated temperature confirmed faecal coliform test.

In Chapter 5 we examined the evidence supporting the assumptions underlying the faecal coliform test and in the Review of Chapter 5 we summarised those assumptions. The major assumptions are that faecal coliforms occur only in faeces and that rivers and other natural waters do not contain faecal coliforms unless the faeces of man or warm blooded animals have entered the waters. Additionally, it is assumed that the presence of faecal coliforms establishes the probability of the presence of pathogens.

This Chapter concludes that the micro-organisms in paper pulp effluent which react as faecal coliforms are a major, rather than a minor, consideration. The micro-organisms may be pathogenic in their own right. They may or may not be faecal in origin; but they are suspect as being such and further examination is required, both of them and of the coliform test to which they react. In the light of present knowledge it appears necessary to regard these micro-organisms as faecal coliforms.

The implications are particularly important to the Derwent River system, as our preliminary work has shown that this paper pulp mill at Boyer is the largest source of faecal coliforms in the section of river studied.

FAECAL COLIFORMS AND THEIR IMPLICATIONS

The two samples that were taken of the pulp and paper mill effluent reacted positively as containing ≥24,000 faecal coliforms/100 ml. If it is assumed that faecal coliforms are mainly E.coli, as Geldreich has claimed,[2] then, as E.coli allegedly only grows in the intestines of warm blooded animals (including man),[3] this effluent should contain large numbers of enteric pathogens (such as Salmonella).[4] This would make it a major health hazard, because of the very large volume of effluent produced (100 Ml/day).[5] This may not be so.

In the environmental conditions that prevail in the carbohydrate-rich effluents from pulp and paper mills,[6] textile finishing mills,[7] and sugar mills,[8] coliforms other than E.coli have been reported to react positively as faecal coliforms as measured by the elevated temperature test. Klebsiella pneumoniae would appear to be the most significant (in terms of numbers and health risks).

Although K.pneumoniae was suggested as an indicator of human faecal contamination of water as long ago as 1880,[9] and it is well-known in clinical medicine as an opportunistic pathogen, causing pneumonia, urinary tract infections, and enteritis (in children),[10] its significance in the microbiology of water seems to have been overshadowed by that of E.coli. Recently, however, simplified procedures for its detection,[11] a more rational taxonomy,[12] and an increase in nosocomial (hospital and nursing-home related) infections,[13] have led to an upsurge of interest in K.pneumoniae, and a re-evaluation of its potential significance.

Studies have shown that the organism is widely distributed in nature,[14] although it does not seem to be ubiquitous in surface waters.[15] It may be detected in eutrophic waters,[16] and grows in carbohydrate-rich waters from a variety of sources.[17] It is more resistant to chlorine than is E.coli.[18]

Several studies have emphasised the similarity of environmental and clinical strains of K.pneumoniae in biochemical, serological and mouse pathogenicity tests.[19 20 21 22] These similarities have led researchers to suggest that Klebsiella pneumoniae in the natural environment may represent the reservoir for the evolution of clinical Klebsiella.[23] This would explain the finding that while multiple antibiotic resistance is less common in environmental than in hospital isolates of K.pneumoniae, it does occur, and in both environmental and clinical isolates it carries with it "a significant percentage of transfer factor possession",[24] suggesting a common origin.

Further, these similarities between the known pathogenic isolates of K.pneumoniae and the environmental isolates have caused concern that the environmental strains might be pathogenic. This concern was deepened by the finding that the incidence of colonization of the human gut by K.pneumoniae has increased over the last twenty years, and so has the incidence of human infection from Klebsiella pneumoniae.[25] It appears that colonization of the gut may be conducive to infection with K.pneumoniae.[26] This has been suggested as the cause of spread of nosocomial infections.[27]

The one marked difference between the pathogenic clinical isolates and the environmental K.pneumoniae isolates seems to be the response to the faecal coliform elevated temperature test. Those studies that have examined the environmental isolates have found that only a small proportion of the bacteria are faecal coliform test positive. One study that compared environmental and clinical isolates for their response to the faecal coliform test found that 83% of the clinical isolates were faecal coliform positive;

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only 16% of the environmental isolates were faecal coliform positive.[28] It regarded these positive 16% as having faecal origin, and stated:"If it is deemed necessary to identify organisms appearing as Fc's on MF or MPN test, Klebsiella should be considered as valid as a Fc as E.coli".[29]

It considered that the presence of K.pneumoniae alone is evidence that faecal contamination has occurred at some time, recent or not; if E.coli too is present, then the contamination is recent. However, it suggested that the significance of K.pneumoniae lies not in its indicating that enteric pathogens such as Salmonella may be present, but in its own opportunistic pathogenicity. This may not be recognised, it stated, because if infection follows gut colonization then there may be a time lag between exposure and infection.[30]

As there has not been any demonstrated increase in infections due to water-borne K.pneumoniae we are hesitant about claiming that it is a water associated pathogen, but, on the present evidence, this cannot be ruled out. Neither do we suggest that K.pneumoniae is necessarily an indicator of the faecal contamination of water, even though it now appears that 30-40 percent of people have it in their gut.[31]

We are suggesting that work both overseas and in Australia[32] has shown that effluent from pulp and paper mills contains high levels of faecal coliform positive K.pneumoniae; that this organism more often has a positive faecal coliform response if it is pathogenic than if it is an environmental isolate;[33] that faecal coliform levels have been shown to be related both to the presence of pathogens in water,[34] and, by epidemiological methods, to health risks in recreational waters;[35] that we found very high levels of faecal coliforms in the effluent from the Boyer newsprint mill; that the levels of faecal coliforms in the river between Boyer and Bridgewater are above those recommended in the water quality criteria discussed earlier in this Report; and that, as a matter of prudence, and in the absence of evidence to the

contrary, the effluent and river below should be regarded as a health hazard.

An additional consideration is that raised by Bloom in his comments on the interaction of organic wastes and heavy metals. We had suggested in the Introduction that animal wastes may be contributing to the organic waste load in the Derwent. We have shown that this is not so. However, it has been reported,[37] that the pulp mill has a daily waste effluent volume of 100 Megalitres with a strength of 350 mg/l BOD and 1200 mg/l suspended solids. This waste is discharged to Lagoons prior to release to the Derwent. Whilst the efficiency of the treatment is unknown, and we have done no testing of it in this Study, our observations indicate it to be low at the times of sampling. The implication of this is, of course, a high volume of organic matter being discharged to the Derwent. The possibility of this matter being available for later interaction with heavy metals should be investigated.

1 *DEPARTMENT OF ENVIRONMENT, HOUSING AND COMMUNITY DEVELOPMENT, 1977;* *Pollution Abatement Costs in the Pulp and Paper Industry;* *Australian Government Publishing Service, Canberra.*

2 *GELDREICH, E.E., 1966;* *Sanitary Significance of Faecal Coliforms in the Environment;* *p. 105;* *Federal Water Pollution Control Administration, U.S. Deaprtment of the Interior, Washington, D.C.*

3 *REPORT, 1969;* *The Bacteriological Examination of Water Supplies, 4th Edition, p.3; Department of Health and Social Securities, Her Majesty's Stationery Office, London.*

4 *HART, B.T., 1974;* *A Compilation of Australian Water Quality Criteria; p.165;* *Australian Water Resources Council Technical Paper No.7, Australian Government Publishing Service, Canberra.*

5 *DEPARTMENT OF ENVIRONMENT, HOUSING AND COMMUNITY DEVELOPMENT, 1977;* *op.cit., p.45.*

6 KNITTEL, M.D., 1972;
Review of research regarding coliforms in pulp and paper mill wastes, in:
BORDNER, R.N., and CARROLL, B.J., (eds.);
Proceedings of the Seminar on the Significance of Faecal Coliforms in Industrial Wastes;
EPA National Field Investigations Centre, 54, Denver, Colorado;
cited in reference 7(below).

7 DUFOUR, A.P., and CABELLI, V.J., 1976;
Characteristics of Klebsiella from textile finishing plant effluents;
Journal of the Water Pollution Control Federation, 48: 872-9

8 NUNEZ, W.J., and COLMER, A.R., 1968;
Differentiation of Aerobacter-Klebsiella isolated from sugar cane;
Applied Microbiology 16: 1875-90.

9 GELDREICH, E.E., 1966; op.cit., p.3.

10 JAWETZ, E., MELNICK, J.L., and ADELBERG, E:A:, 1974;
Review of Medical Microbiology, 11th Edition, p.210;
Lange Medical Publication Los Altos, California.

11 CAMPBELL, L.M., and ROTH, I.L., 1975;
Methyl violet: a selective agent for the differentiation of Klebsiella pneumoniae from Enterobacter aerogenes and other Gram-negative organisms;
Applied Microbiology, 30:258-61.

12 BUCHANAN, R.E., and GIBBONS, N.E., (eds)., 1974;
Bergey's Manual of Determinative Bacteriology, 8th Edition, p.322;
The Williams and Wilkins Company, Baltimore.

13 SELDEN, R., LEE, S., WANG, W.L.L., BENNETT, J.V. and EICKHOFF, T.C., 1971;
Nosocomial Klebsiella infections: intestinal colonisation as reservoir;
Annals of Internal Medicine, 74: 657-64.

14 DUNCAN, D.W., and RAZZELL, W.E., 1972;
Klebsiella biotypes isolated from forest environments and farm produce;
Applied Microbiology, 24:933-38

15 KNITTEL, M.D., 1975;
Occurrence of Klebsiella pneumoniae in surface waters;
Applied Microbiology, 29:595-97

16 CAMPBELL, L.M., MICHAELIS, G., KLEIN, R.D., and ROTH, I.L., 1976;
Isolation of Klebsiella pneumoniae from lake waters,
Canadian Journal of Microbiology, 22: 1762-67.

17 *DUFOUR and CABELLI, 1976; op.cit., p.872.*

18 *PTAK, D.J., GINSBURG, W., and WILEY, B.F., 1973;*
Identification and incidence of Klebsiella in chlorinated water supplies;
Journal of the American Water Works Association, 65:604-608.

19 *SEIDLER, R.J., KNITTELL, M.D. and BROWN, C., 1975;*
Potential pathogens in the environment: cultural reactions and nucleic acid studies on Klebsiella pneumoniae from clinical and environmental sources;
Applied Microbiology, 29:819-25

20 *NUNEZ and COLMER, 1968; op.cit., p.1890.*

21 *DUNCAN and RAZZELL, 1972; op.cit., p.938.*

22 *MATSEN, J.M., SPINDLER, J.A., and BLOSSER, R.O., 1974;*
Characteristics of Klebsiella isolates from natural receiving waters and comparison with human isolates;
Applied Microbiology, 28:672-8

23 *SEIDLER, R.M., MORROW, J.E., and BAGLEY, S.T., 1977;*
Klebsielleae in drinking water from redwood tanks;
Applied and Environmental Microbiology, 33: 893-900

24 *MATSEN, SPINDLER, and BLOSSER, 1974; op.cit., p.678.*

25 *BAGLEY, S.T., and SEIDLER, R.J., 1977;*
Significance of faecal coliform-positive Klebsiella;
Applied and Environmental Microbiology, 33:1141-8

26 *MONTGOMERIE, J.Z., DOAK, P.B., TAYLOR, D.E.M., and NORTH, J.D.K., 1970;*
Klebsiella in faecal flora of renal transplant patients;
Lancet, 2:787-92

27 *EICKHOFF, T.C., 1971;*
Nosocomial infections due to Klebsiella pneumoniae: mechanisms of intra-hospital spread, in:
BRACHMAN, P.S., and EICKHOFF, T.C., (eds),
Proceedings of the International Conference on Nosocomial Infection, pp.117-25;
American Hospital Association, Chicago; cited in:
BAGLEY and SEIDLER, 1977; op.cit., p.1147.

28 *BAGLEY and SEIDLER, 1977; op.cit., p.1146.*

29 *Ibid., p.1147.*

30 *Ibid.*

31 *DAVIS, T.J., and MATSEN, J.M., 1974;*
Prevalence and characterisitics of Klebsiella species. Relation to association with a hospital environment;
Journal of Infectious Diseases, 130:402-405, cited in:
BAGLEY and SEIDLER, 1977; op.cit., p.1141.

[32] *At the Water Research Laboratories, Bolivar, South Australia, Mr. R. Walters (the Senior Microbiologist) is studying the Klebsiella pneumoniae from the effluent of pulp and paper mills near Millicent. Personal communication.*

[33] *BAGLEY and SEIDLER, 1977; op.cit., p.1141.*

[34] *GELDREICH, E.E., 1970;*
Applying Bacteriological parameters to recreational water quality;
Journal of the American Water Works Association, 62: 1113-20

[35] *NCWQ, 1968;*
Report of the National Technical Advisory Committee on Water Quality Criteria, p.12;
Federal Water Pollution Control Administration, U.S. Department of the Interior, Washington, D.C.

[36] *BLOOM, H., 1975;*
Heavy Metals in the Derwent Estuary, p.21;
Chemistry Department, University of Tasmania.

[37] *DEPARTMENT OF THE ENVIRONMENT, HOUSING AND COMMUNITY DEVELOPMENT, 1977; op.cit., p.45.*

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

The aims of this preliminary Study as stated in the Introduction were the determination of the origin of the faecal coliforms observed in the Derwent River at Bridgewater; an assessment of the applicability of the fc:fs ratio to the Derwent/Jordan River Study area; an assessment of the health hazards of the Study area as determined by faecal coliform counts and a characterisation of the Jordan River Basin. This final Chapter presents the Study's findings in the light of the data gathered and with regard to the stated aims. The conclusions drawn are given specifically for faecal coliofrms; for the faecal coliform to faecal streptococci ratio and for health hazard for each study area of the Jordan and Derwent respectively.

The Jordan Basin is found to be a harsh environment for Man and Microbe. This environment is thought to be the reason for the observed low faecal coliform counts in the Jordan River. As the Study was preliminary and covered only the winter season there is much still to be done to obtain a complete and definitive picture. With the data obtained, the broad approach adopted in this Study is no longer necessary, and attention is now focussed on the important aspects as stated in the recommendations.

CONCLUSIONS

Faecal Coliforms.

The Jordan River contributes few faecal coliforms to the River Derwent, probably because the aridity of the catchment and long flow paths means that few faecal coliforms enter the Jordan.

The sewage treatment plant at New Norfolk contributes a large number of faecal coliforms which could indicate the entry of a large number of viral and other pathogens. This is a localized hazard because of the laminar flow affecting only persons near the South bank of the Derwent just below the Plant. Unfortunately, it is located where the Nomad Ski Club have their slalom course.

The effluent from the newsprint mill at Boyer has very high faecal coliform counts. Because of the large volume of effluent from the mill a very large number of faecal coliforms enter the river daily (around 9 x 10^{13} faecal coliforms per day). This is the major source of coliforms in the Derwent between New Norfolk and Bridgewater.

The river water at Site 11 below the mill supports the multiplication of faecal coliforms on incubation. At Site 10 (above the mill), the water did not support the growth of these indicator organisms. As pulp and paper mill effluents are known to be a source of nutrients for microbial growth, it would appear that in addition to being a source of faecal coliforms, the mill effluent is a potential source for further bacterial growth in the river itself, should the water temperature ~~be sufficiently high to permit the~~ and other ecological conditions favour the multiplication of bacteria.

Although the organisms in the effluent react positively to the elevated temperature faecal coliform test, a literature survey suggests that a large proportion of them are probably Klebsiella pneumoniae. This, if true, has significant implications:-

1) K. pneumoniae has long been regarded as an opportunistic pathogen. The finding of this organism as a faecal coliform could mean that, instead of merely indicating the possibility of the presence of pathogens, the faecal coliform elevated temperature test is

directly indicating a potential pathogen. (Water associated Klebsiella pneumoniae has not been implicated in outbreaks of disease despite the similarities between environmental and clinical isolates so it can only be called a potential pathogen).

2) Environmental K. pneumoniae may act as an evolutionary genetic pool for clinical strains; as transfer factors have been found in this group, antibiotic resistance may spread rapidly.

3) K. pneumoniae, unlike E. coli, can multiply outside the gut of warm-blooded animals. Should it multiply in the Derwent the use of faecal coliform water quality criteria, which depend on the non-growth of indicator bacteria in the receiving waters, will be rendered invalid.

Because of these problems more research is needed to define rigorously the faecal coliform group, and the signifocance of each member of the group.

Fc:Fs Ratios.

Although the imbalance between animals and humans in the Jordan Basin was reflected, to a certain extent, in the fc:fs ratios, marked fluctuations in these counts make it difficult to interpret the results with any confidence. The reasons probably lie in the environmental conditions, but the vagaries of the MPN technique may also play a part.

In the Derwent, upstream of Boyer, the fc:fs ratios fluctuated markedly. Even sampling near the New Norfolk sewage treatment plant did not always give results consistent with human waste contamination.

Sampling of the effluent from the newsprint mill gave results that rather destroy ones faith in fc:fs ratios distinguishing between human faecal contamination and

animal faecal contamination. The fc:fs ratios of the effluent indicated the mill to be a large city. Below Boyer the effect of the faecal coliforms from the mill overwhelms all other imputs, leaving no valid basis for using the fc:fs ratio.

We conclude that in the sections of the rivers we studied, the fc:fs ratios were of no real value in deciding whether a source is of animal or human origin. It is evident that great care needs to be taken in the use of this test, and that it should only be interpreted with due regard given to environmental conditions.

Health Hazards.

Our study of the recent literature suggests that present correlations between faecal coliforms and definite health hazards are not based on enough differing environments, and local environmental conditions need to be considered in the formulation of criteria. The criteria recommended at present are based on overseas work, and may therefore be irrelevant or inadequate.

For the criterion for primary body contact recreational waters (bathing waters), we used (inadequate though it may be), 200 faecal coliforms/100 ml. as the upper limit before further investigations should be conducted. We found several sites to be possible health hazards.

Jordan River: the Pontville Ford and the Conservation Area at Herdsman's Cove are possible health hazards. The presence of a treatment lagoon above Herdsman's Cove (and the possible relocation of the Bridgewater sewage treatment plant to upstream of the Cove) is likely to lead to a reservoir of infection in the wildfowl which inhabit the Conservation Area, and may be seen flying from lagoon to Cove.

River Derwent: (1) the South bank adjacent to the New Norfolk sewage treatment plant where the water ski club slalom course is located, and across the river to the launching ramp when there is low river flow.

(2) The River downstream from Boyer to ~~Bridgewater throughout the year~~ Site 11 from June to September. Further investigation might reveal that the section of the River potentially hazardout to health could be extended from Boyer to Bridgewater for most of the year

(3) Out from the New Norfolk Rowing Club boat ramp during the summer months (months of low river flow). this remains, of course, to be confirmed.

Man and River.
The Jordan.

The aridity and the steep terrain of the Jordan have controlled and will continue to control Man's agricultural use of the region.

No areas of the Jordan Basin have sufficient rainfall to ensure adequate crop-plant growth during the growing season. Irrigation is necessary even at Bagdad (615 mm. average rainfall).

If a water storage for irrigation is constructed it is likely to be at Kempton as:-

1) This site is favoured by the Rivers and Water Supply Commission.
2) The Kempton Valley has some of the better soils of the Basin.
3) The rainfall is adequate for a longer proportion of the growing season so only three months irrigation is required, as against five months on similar soils around Brighton.
4) The subdivisional developments around Brighton are likely to restrict future agricultural land development in this area.

If water storage is provided and irrigation increased, it can be anticipated that faecal coliforms will increase in the Jordan from additional runoff in the Green Ponds, the Bagdad, and Strathallan Rivulets.

The Derwent.

This Study has shown that animal wastes contribute little organic matter to the River. However it has also shown that the pulp mill at Boyer may be contributing large quantities and suggests that the quantities and their movements in the receiving waters be examined.

RECOMMENDATIONS

For the River Derwent we recommend a regular sampling programme during the summer months at all bathing beaches or other sites of primary contact recreation. This programme should not only examine for faecal coliforms, but should differentiate further within this group to determine the bacterial species reacting positively to the elevated temperature test. If sampling is extended to include the Salmonella/Shigella group of pathogens and those viruses that can be easily detected, a local set of water quality criteria might be established. As most viruses cannot be readily detected, yet are becoming recognised as probably a major cause of water associated recreational illness, an epidemiological survey among river users could be invaluable in deciding what water quality criteria should be formulated.

A detailed examination of the effluent from the newsprint mill at Boyer in order to determine:-

1) Both the constituents and quantities of nutrients present. Not only will the nutrients determine the limits to bacterial growth, but it may be that it may become economically viable to utilise them.

2) The species present in the microbial population: their origin and their ecology. By determining their ecology it may become possible to manipulate the species present and/or the numbers within each species by minor alterations in the environment. As this study would take a considerable time, we suggest that as a first step, those

organisms in the faecal coliform group in the effluent should have their relationships studied. Testing for enteric pathogens would also be necessary.

Study of the patterns of illness at the mill, especially those of workers coming into intimate and prolonged contact with the effluent. Of particular interest would be the incidence of urinary, gastro-intestinal and respiratory infections. This is necessary to determine the relationship between possible health hazards and health, should the microbiological work show a health hazard exists.

Sampling of the shallows between Boyer and Bridgewater during the summer months to determine whether faecal coliforms multiply there when the water warms.

For the Jordan River we recommend:-

An investigation of the mechanisms which are causing the low faecal organisms counts observed in the River. It is thought the low count is due largely to environmental conditions in the soil, but predation either in soil or creek/river water may be significant. Studies of the microbiology of the soils, animal distribution, run off patterns and creek/river microbial ecology are needed.

The above investigation to be linked to:-

(a) An investigation of the likely impact of increasing animal populations on irrigated pastures so that control measures can be formulated and implemented if found necessary.
(b) An investigation of the recreational amenity of the Jordan in the Herdsman's Cove Conservation Area and the likely effect of increase in human activity.
(c) Sampling for faecal coliforms and pathogens in the River from Pontville Ford to Herdsman's Cove during the summer months.

APPENDICES

APPENDIX ONE

EVAPORATION AND EFFECTIVE RAINFALL

Evaporation

There is no evaporation station in the catchment, the nearest being at Hobart and Lake St. Clair.

The Bureau of Meteorology have used Cressy Research Farm evaporation figures to calculate probable average monthly figures at Oatlands as shown in Table 1.

TABLE 1

Average Monthly Evaporation (mm.)

	Jan.	Feb.	Mar.	April	May	June	July
Cressy	130	107	81	49	30	20	20
Oatlands	104	92	72	56	37	32	31

	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Cressy	29	44	67	93	120	790
Oatlands	38	52	63	79	90	746

These figures are average potential crop evapotranspiration rates and do not require correction. (The published data of the Bureau of Meteorology are class A pan figures and have to be multiplied by a factor of 0.75 to obtain average potential crop transpiration rates).

The Rivers and Water Supply Commission have used Hobart monthly rainfall figures obtained from Meteorological Bureau records against Hobart monthly evaporation and have prepared curves from Meteorological Data. These curves were then applied to the Jordan River Basin with values for local evaporation read off for the appropriate rainfall. These values were then compared with Hobart evaporation +10% for the months October to March and the greater of the two values

taken as being local evaporation. Unaltered Hobart Values were used for the months April to September.[1]

Figure 1 graphs Hobart monthly evaporation (corrected) and Hobart Rainfall for the months October to March, and Table 2 gives Hobart's Average Monthly Evaporation Rates.

TABLE 2

Hobart Average Monthly Evaporation (mm.)

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
120	93	79	50	36	23	24	33	50	74	94	110

Year
786

Effective Rainfall is defined as the amount of rainfall necessary to promote plant germination and to maintain plant growth above the wilting point. Prescott[2] has related effective rainfall to evaporation by the equation:

$$\frac{P}{E^{0.7}} = 0.54$$

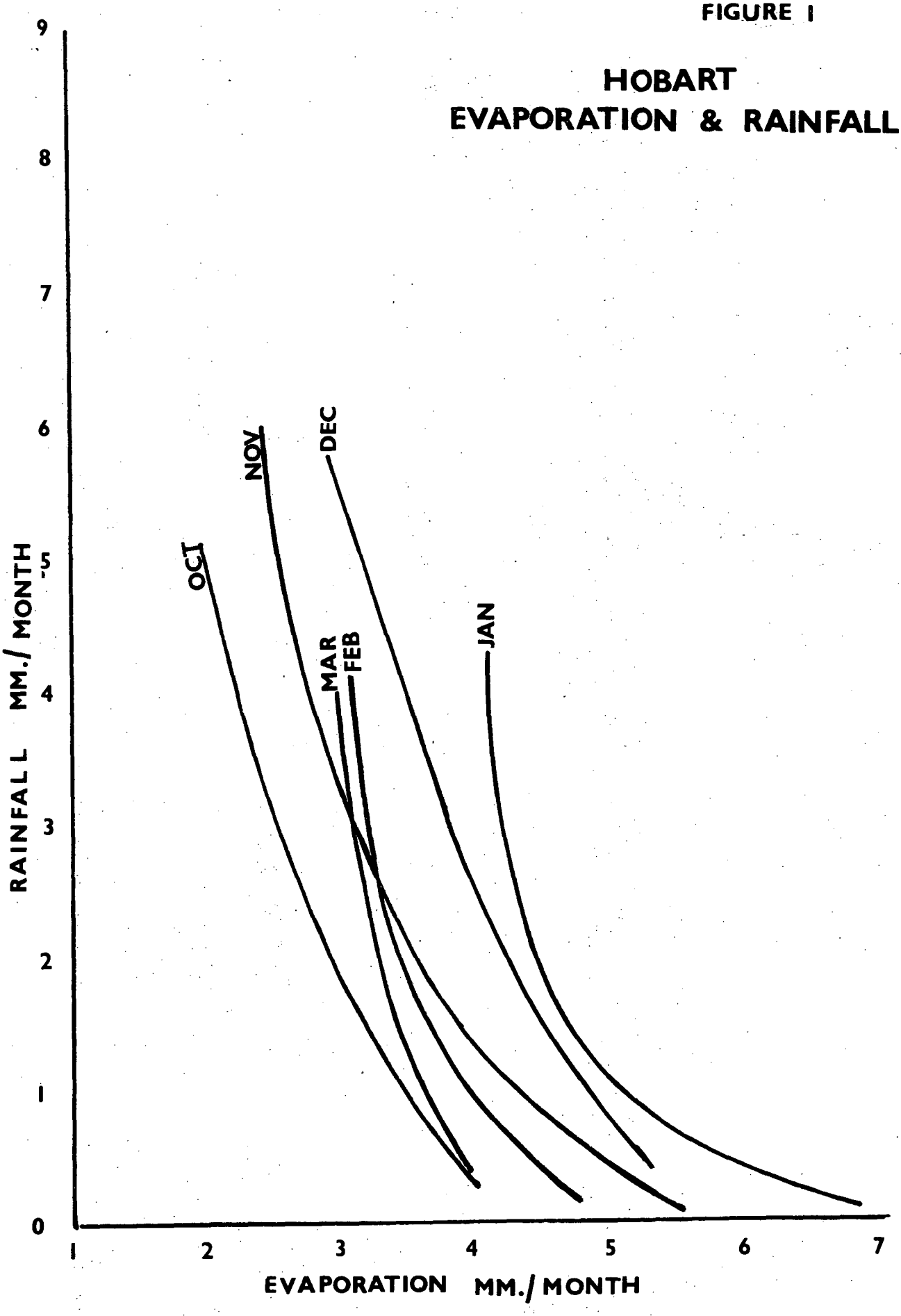
where P is the effective rainfall and E is the evaporation.

The constants 0.7 and 0.54 were originally derived for the wheat growing areas of South Australia. The formula has serious deficiencies in that it does not take account of the varying water storage capacity of the various soils and it is necessary to alter the constant 0.54 to accord with the evapotranspiration of the crop. (e.g. for rice crops values of 2.0 have been used).

Prescott et alia[3] used values of the index $P/E^{0.75}$ to estimate the length of the growing season and found that the length of the growing season as determined by moisture

FIGURE 1

HOBART
EVAPORATION & RAINFALL



conditions can be expressed by the period during which the index $P/E^{0.75}$ exceeds a value of 0.4. Loveday[4] suggests that monthly values of this order are not sufficient to maintain vegetation even of low transpiration and must be supported by substantial periods of time when values of the index are 0.8 or more.

Tyson[5] estimates that water is required for Horticulture for 5 to 6 months per year in the Jordan Valley.

In view of these previous reports we decided to try to establish the likely growing season length at locations on alluvial plains in the Jordan Valley.

The locations chosen were Oatlands, Bagdad and Brighton and the ratio $P/E^{0.75}$ calculated for each as in Table 3.

Since Prescott measured P and E in empirical units it has been necessary to correct the metric values for $P/E^{0.75}$ by dividing by 2.24. $\left(= \frac{25.4}{25.4^{0.75}}\right)$

TABLE 3 CLIMATIC DATA - OATLANDS, KEMPTON AND BRIGHTON

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Av. Rainfall													
Oatlands	44	41	41	48	48	54	41	43	42	58	50	59	569
Bagdad	42	50	47	57	50	54	42	47	43	65	53	65	615
Brighton	44	30	39	49	35	43	35	29	42	52	34	52	484
Av. Evaporation Adjusted from Hobart.													
Oatlands	104	92	72	56	37	32	31	38	52	63	79	90	
Bagdad	125	93	79	50	36	23	24	33	50	74	97	110	
Brighton	126	93	79	50	36	23	24	33	50	80	110	114	
$P/2.24E^{0.75}$													
Oatlands	0.60	0.62	0.74	1.05	1.43	1.79	1.39	2.81	0.97	1.16	0.84	0.90	
Bagdad	0.50	0.75	0.79	1.35	1.52	2.29	1.73	1.52	1.02	1.15	0.76	0.85	
Brighton	0.52	0.44	0.66	1.16	1.06	1.83	1.44	0.94	0.99	0.87	0.45	0.66	
Loveday's calculated ratio for Bream Creek[6] is given for comparison purposes:-													
Bream Creek	0.67	0.89	0.96	1.43	1.30	2.49	1.59	1.35	0.82	1.07	0.95	1.03	

It is clearly evident that Oatlands, Bagdad and Brighton are considerably more arid than Bream Creek in the catchment of the adjacent Coal River Basin.

It can be expected that irrigation will be required in Oatlands from January to March; at Bagdad in January and February and possible part of March, and at Brighton from November to March.

1 *STEANE, J.D., 1967;*
Water Resources of the River Jordan;
Tasmanian Water Resources Survey, Third Report;
Rivers and Water Supply Commission, Hobart.

2 *PRESCOTT, J.A., 1949;*
A climatic index for the leaching factor in soil formation.
Journal of Soil Science, 1:9-19.

3 *PRESCOTT, J.A., COLLINS, J.A., SHIRPURKA, G.R., 1952;*
The comparative climatology of Australia and Argentina;
Geog. Rev., 42: 118-33.

4 *LOVEDAY, J., 1957;*
The soils of the Sorell-Carlton-Copping Area, South East Tasmania with special reference to the soils formed on basalt.
Soils Publication No.8, C.S.I.R.O.

5 *TYSON, R., 1967;*
Jordan River Valley.
Unpublished Report; Tasmanian Department of Agriculture;
Tasmanian Agricultural Department Library.

6 *LOVEDAY, J., 1957; op.cit., p.8.*

APPENDIX TWO

SAMPLING DATA

Temperature, conductivity as salinity, pH and dissolved oxygen are given in the following Table.

Microbiological sampling commenced on the 8th April, '77.

Date		18.2.77	25.2.77	4.3.77	11.3.77	18.3.77	8.4.77*	22.4.77	6.5.77
SITE 1	°C	20	16	20	20	19	13	12	11.5
salinity†		170	370	210	370	320	130	210	230
	pH				5.4	8.4			
	DO		9.2					10.2	11.2
SITE 2	°C	19	18	20	20	19	13	12	12
salinity†		550	550	600	300	450	430	370	460
	pH				6.7	7.8			
	DO		6.0					8.6	9.6
SITE 3	°C	15.5	17	19	19	18	13	12	14.5
salinity†		off scale	off scale	210	320	280	490	210	230
	pH				6.6	7.2			
	DO		5.4					10.2	10.0
SITE 4	°C	18	17	20	20	19	13	12	10
salinity†		600	430	430	320	340	160	190	230
	pH				6.6	7.9			
	DO		7.2					9.8	10.8
SITE 5	°C	18	18	20	20	19	13	12.5	13
salinity†		660	550	430	320	338	130	160	240
	pH				7.0	8.1			
	DO		8.3					11.0	11.4
SITE 6	°C	19	18	19	20	19	13.5	13	12
salinity†		830	540	550	660	580	160	130	320
	pH				7.4	7.8			
	DO		8.0					10.6	10.4
SITE 7	°C	20	20	23	20	19	14	15	14
salinity†		off scale	off scale	off scale	5800	8300	830	660	720
	pH				7.2	8.1			
	DO		8.0					10.2	9.0
SITE 8	°C	20	19	20	20	19	13	13.5	12
salinity†		40	160	30	30	30	30	30	30
	pH				6.6	7.1			
	DO							10.2	10.8
SITE 9	°C	20	19	20	20	19	13	13.5	11
salinity†		70	30	30	320	50	30	160	20
	pH				6.3	7.3			
	DO							10.1	10.5
SITE 10	°C	20	19	20	20	19	13.5	13.5	11
salinity†		410	140	560	940	800	130	320	20
	pH				5.9	7.0			
	DO							10.0	9.6
SITE 11	°C								
salinity†									
	pH								
	DO								

* Beginning of microbiological sampling.

† Conductivity as Salinity as parts per million of soluble salt as NaCl.

Date		20.5.77	3.6.77	17.6.77	1.7.77	15.7.77	19.7.77	12.8.77	2.9.77
SITE 1	°C	10	8	8	5	6.5	6.5		8
salinity†		230	90	130	60	130	70		180
	pH								7.7
	DO	10.8	11.5	11.5	11.5	12.0	11.0		10.8
SITE 2	°C	11	7	8	5	6.7	7.5		9.2
salinity†		490	290	550	370	550	210		490
	pH								8.0
	DO	10.4	11.5	10.6	11.5	11.5	11.2		10.0
SITE 3	°C	10.2	7	9	5	8	7.5		9
salinity†		270	240	320	180	370	210		260
	pH								7.45
	DO	10.8	11.5	10.8	11.5	11.0	11.6		10.8
SITE 4	°C	9	7	6.5	5	5	6.5		10
salinity†		320	140	230	160	320	140		320
	pH								7.6
	DO	10.0	11.2	11.0	11.8	11.4	11.0		10.8
SITE 5	°C	10	8.2	7.7	5	6.7			
salinity†		310	180	260	180	320			
	pH								
	DO	11.0	11.0	11.0	11.8	11.4			
SITE 6	°C	10	8.5	8	6.5	8.5	6		15
salinity†		330	320	340	160	480	210		550
	pH								8.1
	DO	10.5	11.8	11.0	10.8	10.6	12.4		9.8
SITE 7	°C	12	9.5	9.5	7.5	8	8		14
salinity†		off scale	400	780	280	430	210		550
	pH								8.1
	DO	7.6	10.0	11.0	11.8	11.0	10.2		9.8
SITE 8	°C	10	8.5	7.5	7.0	6.5	6		9
salinity†		30	10	80	30	30	10		30
	pH								7.0
	DO	10.4	11.4	11.0	11.4	11.8	12.0		10.0
SITE 9	°C	10	9.5	7	7	6.5	6		9
salinity†		160	10	30	30	30	20		30
	pH								7.0
	DO	9.4	11.0	11.0	12.5	11.8	12.0		10.0
SITE 10	°C	10	9.5	7	7	8	6.2		10
salinity†		660	30	30	30	30	20		30
	pH								6.8
	DO	9.0	10.3	11.0	11.8	11.0	11.4		10.7
SITE 11	°C		8	7	7	6			10
salinity†			90	490	140	640	not taken		430
	pH								7.1
	DO		11.0	11.0	11.4	11.8			9.8

* Beginning of microbiological sampling.

† Conductivity as Salinity as parts per million of soluble salt as NaCl.